FOREWORD

DNV GL standards contain requirements, principles and acceptance criteria for objects, personnel, organisations and/or operations.
Changes – Current

General

This document supersedes DNV-OS-E406, April 2010.

Text affected by the main changes in this edition is highlighted in red colour. However, if the changes involve a whole chapter, section or sub-section, normally only the title will be in red colour.

On 12 September 2013, DNV and GL merged to form DNV GL Group. On 25 November 2013 Det Norske Veritas AS became the 100% shareholder of Germanischer Lloyd SE, the parent company of the GL Group, and on 27 November 2013 Det Norske Veritas AS, company registration number 945 748 931, changed its name to DNV GL AS. For further information, see www.dnvgl.com. Any reference in this document to “Det Norske Veritas AS”, “Det Norske Veritas”, “DNV”, “GL”, “Germanischer Lloyd SE”, “GL Group” or any other legal entity name or trading name presently owned by the DNV GL Group shall therefore also be considered a reference to “DNV GL AS”.

Main changes

- General
  The following have been implemented in this revision of the document:
  - Recalibrated load factor requirements for the ultimate limit state (ULS) and accidental limit state (ALS), reflecting the removal of the distinction between fully and partly submerged lifeboats and the knowledge gained from new computational fluid dynamics (CFD) analyses of lifeboat launches.
  - A reorganized materials section, including making the informative appendix on manufacturing into a normative subsection.
  - A rephrased no-collision requirement and specified limitations on the use of the substitute requirement for distance at resurfacing.
  - Updated and expanded requirements for human load measures.
  - Modified test requirements to reflect developments within CFD analysis.
  - The entire section on the qualification of new free-fall lifeboat concepts has been replaced by a one-clause recommendation of such qualification.
  - Detailed text sequences have been replaced by references to other DNV documents.

- Sec.1 Introduction
  - Sec.1 has been re-arranged and compressed.

- Sec.3 Environmental conditions
  - In [3.3.3], the text regarding the calculation of wave heights with specified return periods has been revised for clarity. To avoid duplication of information, very detailed texts regarding waves and current in [3.3.4] and [3.4.3] have been replaced by references to DNV-RP-C205.
  - In [3.5.1.1], the figure for water level definitions has been replaced by an improved figure for clarity.
  - In [3.6.1], a reference to DNVGL-OS-A201 for the assessment of ice accretion has been added.

- Sec.4 Loads and load effects
  - In [4.4.3], the requirements for the design of railings have been changed to bring them in line with requirements in DNV Offshore Standards.
  - In [4.5.2], text regarding wind loading has been clarified.
  - In [4.5.2.9], a specification has been included stating that wind coefficients for the six degrees of freedom are needed in order to calculate wind forces and moments.
  - In [4.5.2.10], the requirement not to account for reduction in wind velocity due to possible shielding effects has been relaxed, so that such reductions may now be considered. A warning has been included that wind velocity can be enhanced on the lee-side of the host structure too. The guidance note has been simplified.
— In [4.5.3], the term “log dive” has been introduced to describe two of the three motion patterns that are categorized as unacceptable.

— In [4.5.3.4], the list of parameters that can influence the motion pattern and possible log dive behaviour has been expanded. The former Figure 8 showing the relationship between motion pattern and governing parameters has been removed.

— In [4.5.3.5], the guidance note has been extended and rewritten for clarification and a new Figure 4-8 showing the velocity indicators for log dive has been included.

— In [4.5.6.6], the guidance note has been removed as obsolete.

— In [4.5.8.2], the guidance note has been removed as obsolete after the removal of items E808 to E817.

— Items E808 through E817, which contained a lot of guidance material on how to establish hydrodynamic pressure load distributions, have been removed. Much of this material belongs in a textbook rather than in a design standard. Some of the material was only approximate. The items have been replaced by a new item [4.5.8.8], specifying that CFD analysis can be used to establish hydrodynamic pressure load distributions.

— In [4.10.1.1], the load factor 1.3 for G and Q loads has been replaced by 1.0. The load factor 1.3 represents an unintentional mistake made while the standard was being developed. The load factor 1.0 will be consistent and in equilibrium with the other forces that the lifeboat will experience during its launch and is what is being used in current designs.

— In the former Sec.4 J103, the distinction between fully and partly submerged lifeboats in the design stage has been removed and the requirements for ULS and ALS designs have been updated accordingly. The distinction cannot be justified physically and the updated requirements for ULS and ALS designs form a more transparent approach. A new definition of characteristic loads for the ALS has been introduced as part of this change. The load factor requirements in the former Sec.4 J103 have been recalibrated accordingly. This recalibration has capitalized on available model test data as well as on new CFD analysis data which have become available since the 2010 revision of the standard.

• Sec.5 Material selection and manufacturing

— In [5.3.2], Tables C2 and C3 for conversions between NV steel grades and EN10025 steel grades have been replaced by one common updated Table 5-6 Steel grade conversions.

— In [5.3.2], Tables C4 and C5 for steel grades as a function of thickness and temperature have been replaced by references to DNVGL-OS-B101 Ch.2 Sec.1.

— In [5.3.3], a new subsection for bolting materials has been introduced.

— In [5.4.1], the tables for aluminium properties have been replaced by references to DNVGL-OS-B101 Ch.2 Sec.5.

— In [5.5], a new subsection on the manufacturing of metallic structures has been introduced.

— In [5.6], the former subsection E on composite materials has been renamed “Laminates”. Tables with requirements for various raw materials and for testing have been replaced by references to DNV Rules for High Speed, Light Craft and Naval Surface Craft. Requirements for production and inspection have been removed.

— In [5.6.5], the requirement for a chemical analysis to show that requirements for a particular composition of E glass are met is replaced by a requirement for a chemical analysis to document the chemical composition. The rationale behind this change is to not exclude glass fibre materials with more modern chemical compositions than the particular one referenced.
— In [5.7], the former subsection F on sandwich materials has been renamed “Sandwich Structures”. Tables with requirements for material properties have been replaced by references to DNV Rules for High Speed, Light Craft and Naval Surface Craft. Requirements for production and inspection have been removed. Requirements for expanded foam have been introduced.
— The former informative Appendix B has been updated and moved to Sec.5 to form a new subsection [5.8] with requirements for the manufacturing of FRP composite structures. The subsequent appendix has been renumbered.

• Sec.6 Structural design
— In [6.1.3] a total of five statements, specifying which type of limit state (ULS or SLS) is reached when a functional requirement is not met in design, have been removed as unnecessary.
— The former Sec.6 A405 has been removed as unnecessary.
— [6.1.8]: For primary and secondary means of launching separate DNV-OS-E406 specific design requirements have been removed, leaving only specifications to fulfil requirements for the design of such means given in NORSOK R-002, thereby avoiding the duplication of requirements and potential contradiction between requirements.
— In [6.1.10], a new clause has been included addressing the possibility of using enclosures as a method to protect the lifeboat from ice accretion.
— In the former Sec.6 B700, item 701 has been deleted as a duplication of [6.2.5.2] and the former 702 and 703 have been moved to [6.2.5].
— [6.2.7] has been replaced by a reference to DNVGL-OS-C101.
— In [6.2.8], major parts have been replaced by references to DNVGL-OS-C101 and DNV Rules for HSLC.
— [6.3.8.7] has been modified to clarify that the nominal bearing stress is the characteristic nominal bearing stress.

• Sec.7 Operational requirements
— In [7.2.2.1], the text about fast and efficient boarding has been removed from the guidance note as its implementation was not very practical. The part dealing with symmetrical loading of the lifeboat is adequately covered by [7.2.2.3].
— In [7.3.1.2], a new guidance note has been included to explain the hang-off system.
— In [7.4.2.3], the no-collision requirement has been rephrased, as have the limitations specified in the guidance note for when this requirement can be fulfilled by meeting a substitute requirement for a minimum distance. The substitute requirement can only be used for preliminary design, not final design.
— A new clause [7.5.1.4] has been introduced to draw attention to the possibility that CFD analysis can be used to document the behaviour of the lifeboat during the sailing phase.
— In [7.5.3], the characteristic sea state for specification of headway tests has been replaced by a more relaxed test sea state, which is more realistic for conducting full-scale tests.
— In [7.5.3.4], a requirement has been included to vary the direction of wind relative to the direction of waves between 0 and 20°.
— In [7.5.3.5] and [7.5.3.6], the requirement to assume collinearity between wind and waves has been replaced by a requirement to vary the direction of wind relative to the direction of waves between 0 and 20°.
— In [7.5.3.6], a guidance note has been included stating that the maintenance of manoeuvring control of the lifeboat can be demonstrated by simulating a circular manoeuvre with a defined diameter in the specified 100-year sea state.
— The original requirement in [7.5.6.2] for the lifeboat to be compatible with the latest generation of standby vessels with docking systems for lifeboats is hard to meet in practice and should rather be a requirement for new standby vessels. The requirement has therefore been replaced by a recommendation of such compatibility.

• Sec.8 Occupant safety and comfort
— In [8.2.2.1], Table 8-1 has been expanded by including body measures for the Hybrid III median male dummy. As far as possible, such measures have also been included for the RID3D dummy. The seat design requirements in [8.2.2.1] have been tightened up by requiring at least one seat to be designed
for the maximum occupant and one seat to be designed for the minimum occupant. A recommendation has been included that the requirement for the design of the seats to suit a range of persons within the minimum and maximum characteristic properties specified in Table B1 can be fulfilled by using adjustable seats and seat belts fitting all sizes.

— In [8.2.3], statements are included to clarify that accelerations for the CAR measure refer to accelerations of the lifeboat seat, whereas accelerations for the HIC36 measure refer to accelerations of the human head (or the head of human surrogates in tests).

— In [8.2.4.2], critical force values previously given in the list of variables in item text have been moved into a new Table 8-2.

— In [8.2.6], Table 8-3 has been updated so the descriptions and explanations of the various AIS codes comply with terms used by relevant websites such as www.trauma.org.

— In [8.2.7.13], Table 8-4 has been updated with new requirements for human load measures for various body parts in the RID3D median male dummy in order to reflect the results of recent research. Likewise a new item [8.2.7.14] with a new Table 8-5 has been included with similar requirements for human load measures referring to various body parts in the 5th percentile female and Hercules large size male. Requirements for pelvis accelerations have been removed as they do not correlate well to injury and are not used anymore. Requirements for Nij have been removed as other requirements cover their purpose.

— In [8.2.7.15], a statement has been included that the requirements for HIC36 in Table 8-4 and Table 8-5 have to be used with caution because the critical values of HIC36 are very sensitive to the actually selected seat and harness systems.

— In [8.2.9.6] and [8.2.9.7], the requirements for a releasable and transportable seat for injured occupants have been relaxed to form a recommendation only. The justification for this relaxation is that such a seat may be hard to lift and transport to and from the lifeboat and this may cause delays in the launch of the lifeboat in an emergency situation.

— In [8.3.1.3], a guidance note has been added to clarify that when the lifeboat is used as a muster area, the requirements for the muster area given in [7.2.1] become requirements for the lifeboat too.

— In [8.3.3.2], the CO2 requirement has been changed from maximum 3000 ppm to maximum 5000 ppm. It has been added that a requirement of a minimum fresh air supply shall be established based on the CO2 requirement in conjunction with the need for fresh air as a function of an adequate stress factor.

— [8.3.3.3] has been rearranged for clarity and to better reflect the original hearing comments received in 2008.

— In [8.3.4.5], the guidance note has been supplemented with (1) a recommendation of a luminance emittance of 100 lux for System B with a possibility for dimming and (2) a statement that sufficient light in the walkway and to read instructions is important, while too bright a light may be perceived as uncomfortable.

• Sec.9 Model-scale testing and full-scale testing

— In [9.1.1], the introductory text has been modified in light of the developments within CFD modelling since 2009.

— In [9.1.1.2], the text on the need for model tests has been modified to distinguish between the situations with and without available CFD analyses.

— In [9.2.2.3], the requirements for tests in regular and irregular seas have been relaxed, such that only tests in calm water are required. A statement is given that tests in regular or irregular waves may be required depending on the purpose of the tests.

— In [9.2.2.7], clarifications regarding wind coefficients have been implemented.

— [9.2.2.10] has been modified to highlight that wind can be excluded from launch tests in following sea when it is documented that the effect is negligible.

— In [9.2.3.4], the detailed bullet point list for wave-modelling requirements has been replaced by a reference to DNV-RP-C205.

— In [9.2.3.7] and [9.3.3.4], the general recommendation of a minimum sampling rate of 200 Hz for accelerometers is changed to 800 Hz. The recommendation of minimum 1000 Hz for slamming panels is changed to 3000 Hz. These changes reflect current practice.

— In [9.2.3.7] and [9.3.3.4], the special recommendations for the sampling rate for accelerometers have been changed from not less than 2000 Hz to preferably 20 000 Hz and not less than 10 000 Hz. This
Changes – current

— In [9.2], it has been clarified that the level of model testing depends on whether or not CFD analyses are available for establishing characteristic values for use in design. It has also been clarified that Table 9-1 and Table 9-2 refer to a situation where model tests are used as the basis for establishing characteristic values for use in design, i.e. the situation where CFD analyses are not available for this purpose.

— [9.2.3.6], has been subject to a clean-up of confusions between requirements and recommendations: everything in this clause is meant to be a recommendation only.

— In [9.2.4.3], a statement has been added that special attention shall be given to the situation where the lifeboat is subject to a heel about its longitudinal axis when it is to be launched from the lifeboat station on a floater subject to heel and trim as specified.

— [9.3.2.2], statements regarding the need to record metocean parameters during full-scale testing have been replaced by recommendations of such recording.

— In [9.3.2.3], a recommendation has been added that the skid arrangement in tests should be sufficiently stiff that skid deflections do not influence test results.

— In [9.3.4.2], the guidance note with a recommendation to execute one excess height launch test has been turned into a new item [9.3.4.3] with a requirement to execute one such excess height launch test.

— Table 9-3 has been slightly restructured for clarity.

— [9.3.4.5] has been cleaned up by removing all recommendations which are covered elsewhere in the standard, retaining only the single requirement of a structural inspection after launch testing.

— [9.4.2.2] has been supplemented by mentioning ultrasound as a test method and by including a requirement that inspections of FRP structures shall be carried out by an independent surveyor experienced in FRP construction.

— The clause about manoeuvring tests in the former Sec.9 D500 (under acceptance tests) has been moved to form a new item [9.3.8] (under prototype tests) since this test is carried out for a prototype lifeboat, not for each manufactured lifeboat.

— A new subsection [9.5] has been introduced addressing commissioning tests and referring to requirements in NORSOK S-001 and R-002. The purpose is to obtain compatibility with NORSOK. This has no consequences as long as acceptance tests are carried out on the host facility. NORSOK's requirement of a test for a 220% load is particularly mentioned.

• Sec.11 Equipment

— Clarifications have been made several places in Sec.11 regarding the interpretations of an empty lifeboat and fully loaded lifeboat.

— In [11.1.10], additional requirements for the water spray system have been added.

— In [11.1.11.1], the second sentence stating a requirement for how the engine shall draw air has been removed. The requirement was in conflict with the guidance note in [8.3.3.2] and compliance with it was not practicable. A new requirement that the engine shall be designed such that it can draw air from sources other than the cabin has been added.

— In [11.1.11.8], a statement has been added that if the engine draws air from the cabin, the corresponding shutting device for the air intake shall be installed at the air inlet to the cabin. This applies when the air intake to the cabin comes from outside, but not if it is from an emergency air system such as air bottles.

— In [11.1.14], the minimum requirements for ingress protection of electrical equipment have been changed from IP67 outside and IP56 inside to IP66 and IP55 respectively, thereby making the standard consistent with NORSOK R-002.

— In [11.1.17.12], a guidance note has been added, specifying that adequate propeller protection can be achieved by implementing a steering nozzle.

• App.A Interpretation of probability distribution and characteristic values from empirical data

— App.A has been modified to reflect that empirical distribution data may come not only from model tests, but also from CFD analyses.
Editorial corrections
In addition to the above stated main changes, editorial corrections may have been made.

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SECTION 1 INTRODUCTION

1.1 General

1.1.1 Objectives

1.1.1.1 This standard specifies general principles, requirements and guidelines for the site-specific design of free-fall lifeboats and their launching appliances, such as skids, davits and release units. In this respect, the standard has three main areas of focus, viz.

— structural safety, i.e. the safety of the hull and canopy against structural failure
— human safety, i.e. limitation of accelerations of the human body
— headway, i.e. sufficient forward speed after launch.

Guidance note:
Site-specific design implies design for the particular conditions prevailing at the location of the offshore host facility on which the lifeboat is to be installed and used. These conditions include, but are not limited to, the site-specific metocean conditions as well as the launch height implied by the geometry of the host facility and the physical location of the lifeboat on the facility.

1.1.1.2 The objectives of this standard are to:

— provide an internationally acceptable safety standard for free-fall lifeboats by defining minimum requirements for the design, materials, fabrication, testing, operation, repair and requalification of free-fall lifeboats
— specify requirements for lifeboat stations and launching appliances to the extent necessary for the design of free-fall lifeboats
— serve as a technical reference document in contractual matters between the purchaser and contractor
— serve as a guideline for designers, purchasers, contractors and regulators.

1.1.2 Scope and application

1.1.2.1 The standard applies to the design, materials, fabrication, testing, operation, repair and requalification of free-fall lifeboats and their launching appliances.

1.1.2.2 The standard is not applicable to the design of an evacuation system as a whole. This limitation reflects that free-fall lifeboats and their launching appliances only constitute parts of an evacuation system. Lifeboats and their launching appliances shall be compatible with and have an interface with escape routes, muster stations, communication systems, power supply systems, lighting and other features of the host facility which are not covered by this standard.

1.1.2.3 The standard is not applicable to the design of davit-launched lifeboats.

Guidance note:
This limitation reflects the difference between free-fall lifeboats and davit-launched lifeboats, e.g. when it comes to loads and modes of operation.

1.1.2.4 The standard is not applicable to the design of lifeboats on host facilities located in waters where sea ice or ice floes occur.

1.1.2.5 The standard is not part of the technical basis for DNV GL classification or maritime statutory compliance services. Governmental legislation may stipulate requirements differing from the provisions of this standard.

1.1.3 Quality assurance

1.1.3.1 The safety format used in this standard requires that gross errors, such as human errors and organizational errors, shall be handled by requirements for the organization of the work, competence of the personnel performing the work, verification of the design, and quality assurance during all relevant phases.
1.1.3.2 For the purpose of this standard, it is assumed that the owner of lifeboat or lifeboat system has established a quality objective. In all quality-related aspects, the owner shall seek to achieve the quality of products and services intended by the quality objective. Further, the owner shall provide assurance that the intended quality is being, or will be, achieved.

1.1.3.3 A quality system shall be applied to facilitate compliance with this standard’s requirements.

Guidance note:
ISO 9000 provides guidance regarding the selection and use of quality systems.

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1.1.3.4 It is a prerequisite for the design of free-fall lifeboats according to this standard that an efficient quality assurance system is in place, covering all critical production processes involved in the manufacturing of a lifeboat.

1.1.4 Other codes

1.1.4.1 In the case of conflict between this standard’s requirements and a reference document, this standard’s requirements shall prevail.

1.1.4.2 Wherever reference is made to other codes, the latest revision of the code in question shall be applied, unless otherwise specified.

1.1.4.3 When code checks are performed according to codes other than DNV GL codes, the partial safety factors specified in the codes in question shall be used.

1.1.4.4 The prerequisite for using non-DNV GL codes is that the same safety level as the one resulting from designs according to this standard is achieved.

1.1.5 Equivalence and future developments

1.1.5.1 This code specifies requirements for the design of free-fall lifeboats intended to ensure a safety level that is deemed acceptable for lifeboats on offshore installations. Some of these requirements imply certain constraints on lifeboat designs that reflect current practice in the industry and established principles for the design and construction of free-fall lifeboats. Alternative designs and arrangements that deviate from these requirements may be accepted provided a sound engineering analysis documents that the level of safety is at least as high as that implied by the requirements of this code. Basic premises for such analyses should be that the availability on demand of the lifeboat exceeds 99% and that all cost-effective risk control options have been implemented.

Guidance note:
A recommended method for identifying risk control options and documenting the safety of alternative designs and arrangements can be found in DNV-RP-A203. Risk acceptance criteria may be those according to IMO MSC/Circ.1023-MEPC/Circ.392 Guidelines for Formal Safety Assessment. An updated consolidated version may be found in MSC83/INF.2.

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1.1.5.2 Novel future lifeboat concepts may require special attention. It is recommended that a qualification be carried out in the design phase for all novel lifeboat concepts, for all lifeboat concepts that contain one or more novel components, and for all skid and release arrangements with one or more novel components.

Guidance note:
Wherever a concept’s components are novel, the degree of immaturity of those components can be identified through the technology qualification procedure given in DNV-RP-A203. Appropriate risk identification procedures such as HAZID and FMECA can then be applied to assess the risks associated with the novel components.
1.2 References

1.2.1 General

1.2.1.1 The DNV GL documents listed in Table 1-1 and Table 1-2 and the recognized codes and standards in Table 1-3 are referred to in this standard.

1.2.1.2 The latest valid revision of each of the DNV reference documents in Table 1-1 and Table 1-2 applies.

Table 1-1 DNV GL offshore standards, rules for classification and rules for certification

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNV-OS-C501</td>
<td>Composite Components</td>
</tr>
<tr>
<td>DNV Standard for Certification No. 2.20</td>
<td>Lifeboats and Rescue Boats</td>
</tr>
<tr>
<td>DNV Standard for Certification No. 2.22</td>
<td>Lifting Appliances</td>
</tr>
<tr>
<td>DNVGL-OS-A201</td>
<td>Winterization for cold climate operations</td>
</tr>
<tr>
<td>DNVGL-OS-B101</td>
<td>Metallic materials</td>
</tr>
<tr>
<td>DNVGL-OS-C101</td>
<td>Design of offshore steel structures, general - LRFD method</td>
</tr>
<tr>
<td>DNVGL-OS-C401</td>
<td>Fabrication and testing of offshore structures</td>
</tr>
<tr>
<td>DNVGL-OS-D301</td>
<td>Fire protection</td>
</tr>
<tr>
<td>DNVGL-RU-HSLC</td>
<td>DNV GL rules for classification: High speed and light craft</td>
</tr>
</tbody>
</table>

Table 1-2 DNV GL recommended practices and classification notes

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNV-RP-A203</td>
<td>Technology Qualification</td>
</tr>
<tr>
<td>DNV-RP-C201</td>
<td>Buckling Strength of Plated Structures</td>
</tr>
<tr>
<td>DNV-RP-C202</td>
<td>Buckling Strength of Shells</td>
</tr>
<tr>
<td>DNV-RP-C205</td>
<td>Environmental Conditions and Environmental Loads</td>
</tr>
<tr>
<td>DNV Classification Notes 30.1</td>
<td>Buckling Strength Analysis of Bars and Frames, and Spherical Shells</td>
</tr>
<tr>
<td>DNV Classification Notes 30.6</td>
<td>Structural Reliability Analysis of Marine Structures</td>
</tr>
<tr>
<td>DNV Classification Notes 30.7</td>
<td>Fatigue Assessments of Ship Structures</td>
</tr>
</tbody>
</table>

Table 1-3 Other references

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISC</td>
<td>LRFD Manual of Steel Construction</td>
</tr>
<tr>
<td>ASTM C297</td>
<td>Standard Test Method for Flatwise Tensile Strength of Sandwich Constructions</td>
</tr>
<tr>
<td>ASTM D1002</td>
<td>Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)</td>
</tr>
<tr>
<td>ASTM D3163</td>
<td>Standard Test Method for Determining Strength of Adhesively Bonded Rigid Plastic Lap-Shear Joints in Shear by Tension Loading</td>
</tr>
<tr>
<td>ASTM D3528</td>
<td>Standard Test Method for Strength Properties of Double Lap Shear Adhesive Joints by Tension Loading</td>
</tr>
<tr>
<td>BS 7910</td>
<td>Guide on methods for assessing the acceptability of flaws in fusion welded structures</td>
</tr>
<tr>
<td>EN 586</td>
<td>Aluminium and aluminium alloys - Forgings - Part 3: Tolerances on dimensions and form</td>
</tr>
<tr>
<td>EN 1993-1-1</td>
<td>Eurocode 3: Design of Steel Structures, Part 1-1: General Rules and Rules for Buildings</td>
</tr>
<tr>
<td>EN 1999-1-1</td>
<td>Eurocode 9: Design of Aluminium Structures, Part 1-1: General – Common Rules</td>
</tr>
<tr>
<td>EN 10204</td>
<td>Metallic products – types of inspection documents</td>
</tr>
<tr>
<td>EN 10025-2</td>
<td>Hot rolled products of structural steel. Technical delivery conditions for non-alloy structural steels.</td>
</tr>
<tr>
<td>EN 10025-3</td>
<td>Hot rolled products of structural steels. Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels.</td>
</tr>
<tr>
<td>ENV 1090-1</td>
<td>Execution of steel structures ¼ Part 1: General rules and rules for buildings</td>
</tr>
<tr>
<td>ENV 1090-5</td>
<td>Execution of steel structures – Part 5: Supplementary rules for bridges</td>
</tr>
</tbody>
</table>
### Definitions

#### 1.3.1 Verbal forms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>shall</td>
<td>verbal form used to indicate requirements strictly to be followed in order to conform to the document</td>
</tr>
<tr>
<td>should</td>
<td>verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required</td>
</tr>
<tr>
<td>may</td>
<td>verbal form used to indicate a course of action permissible within the limits of the document</td>
</tr>
</tbody>
</table>

#### Table 1-3 Other references (Continued)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 60079</td>
<td>Explosive atmospheres</td>
</tr>
<tr>
<td>IEC 60529</td>
<td>Degrees of protection provided by enclosures (IP code)</td>
</tr>
<tr>
<td>IMO MSC83/Inf.2</td>
<td>Formal Safety Assessment</td>
</tr>
<tr>
<td>IMO MSC/Circ.1023–MEPC/Circ.392</td>
<td>Guidelines for Formal Safety Assessment</td>
</tr>
<tr>
<td>IMO MSC.1/Circ.1206</td>
<td>Measures to prevent accidents with lifeboats</td>
</tr>
<tr>
<td>IMO Resolution MSC.48 (66)</td>
<td>International Life-Saving Appliance Code</td>
</tr>
<tr>
<td>IMO Resolution MSC.81(70)</td>
<td>Revised Recommendation on Testing of Life-Saving Appliances</td>
</tr>
<tr>
<td>ISO 1922-81</td>
<td>Cellular Plastics – Determination of Shear Strength of Rigid Materials</td>
</tr>
<tr>
<td>ISO 3522</td>
<td>Aluminium and aluminium alloys - Castings - Chemical composition and mechanical properties</td>
</tr>
<tr>
<td>ISO 9000</td>
<td>Quality management systems – Fundamentals and vocabulary</td>
</tr>
<tr>
<td>ISO 12100</td>
<td>Safety of machinery – General principles for design – Risk assessment and risk reduction</td>
</tr>
<tr>
<td>ISO 14119</td>
<td>Safety of machinery – Interlocking devices associated with guards – Principles for design and selection</td>
</tr>
<tr>
<td>ISO 17776</td>
<td>Guidelines on tools and techniques for hazard identification and risk assessment</td>
</tr>
<tr>
<td>NAFEMS</td>
<td>Benchmark Tests (several volumes)</td>
</tr>
<tr>
<td>NOROG Guidelines No. 2</td>
<td>Recommended Guidelines for Safety and Emergency Preparedness Training</td>
</tr>
<tr>
<td>NORSOK N-004</td>
<td>Design of Steel Structures</td>
</tr>
<tr>
<td>NORSOK R-002</td>
<td>Lifting Equipment</td>
</tr>
<tr>
<td>NORSOK S-001</td>
<td>Technical Safety</td>
</tr>
<tr>
<td>NORSOK S-002</td>
<td>Working Environment</td>
</tr>
<tr>
<td>OLF LBP2-R001</td>
<td>Minimal Strength Test Procedure for Free Fall Lifeboat Seats</td>
</tr>
<tr>
<td>SAE J211</td>
<td>Recommended Practice: Instrumentation for impact tests</td>
</tr>
</tbody>
</table>
### 1.3.2 Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>accidental limit states (ALS)</td>
<td>excessive structural damage as a consequence of accidents, such as a collision, grounding, explosion or fire, which affect the safety of the structure, environment and personnel. Design against the ALS shall ensure that the structure resists accidental loads and maintains its integrity and performance following local damage or flooding.</td>
</tr>
<tr>
<td>ALARP</td>
<td>as low as reasonably practicable; notation used for risk</td>
</tr>
<tr>
<td>cathodic protection</td>
<td>a technique to prevent corrosion of a steel surface by making the surface the cathode of an electrochemical cell</td>
</tr>
<tr>
<td>characteristic load</td>
<td>the reference value of a load to be used when determining the design load. The characteristic load is normally defined as a specific quantile in the upper tail of the distribution function for load. The quantile is specified by stating the corresponding probability of exceedance in the distribution; for example, the 99% quantile is specified by having 1% (= 10^-2) probability of exceedance. It is important not to confuse this probability of exceedance with any failure probability.</td>
</tr>
<tr>
<td>characteristic load effect</td>
<td>the reference value of a load effect to be used when determining the design load effect. The characteristic load effect is normally defined as a specific quantile in the upper tail of the distribution function for the load effect.</td>
</tr>
<tr>
<td>characteristic material strength</td>
<td>the nominal value of a material strength to be used when determining the design strength. The characteristic material strength is normally defined as a specific quantile in the upper tail of the distribution function for material strength.</td>
</tr>
<tr>
<td>characteristic resistance</td>
<td>the reference value of a structural strength to be used when determining the design resistance. The characteristic resistance is normally defined as a specific quantile in the lower tail of the distribution function for resistance.</td>
</tr>
<tr>
<td>characteristic value</td>
<td>a representative value of a load variable or resistance variable. For a load variable, this is a high but measurable value with a prescribed probability of not being unfavourably exceeded during some reference period. For a resistance variable, this is a low but measurable value with a prescribed probability of being favourably exceeded.</td>
</tr>
<tr>
<td>classification notes</td>
<td>the classification notes cover proven technology and solutions which are found to represent good practice by DNV, and which represent one alternative for satisfying the requirements stipulated in the DNV Rules or other codes and standards cited by DNV. The classification notes will in the same manner be applicable for fulfilling the requirements in the DNV Offshore Standards.</td>
</tr>
<tr>
<td>coating</td>
<td>metallic, inorganic or organic material applied to material surfaces to prevent corrosion or other degradation or both</td>
</tr>
<tr>
<td>contractor</td>
<td>a party contractually appointed by the purchaser to fulfil all or any of the activities associated with fabrication and testing</td>
</tr>
<tr>
<td>corrosion allowance</td>
<td>extra steel thickness that may rust away during the design lifetime</td>
</tr>
<tr>
<td>current</td>
<td>a flow of water past a fixed point and usually represented by a velocity and a direction</td>
</tr>
<tr>
<td>design brief</td>
<td>an agreed document where the owner's requirements in excess of this standard should be stated</td>
</tr>
<tr>
<td>design life, design lifetime</td>
<td>the period of time over which the lifeboat is designed to provide at least an acceptable minimum level of safety, i.e. the period of time over which the lifeboat is designed to meet the requirements set forth in the standard</td>
</tr>
<tr>
<td>design temperature</td>
<td>a unit's design temperature is the reference temperature to be used to determine the areas where the unit can be transported, installed, stored and operated. The design temperature shall be lower than or equal to the lowest daily mean air temperature at the relevant areas.</td>
</tr>
<tr>
<td>design value</td>
<td>the value to be used in the deterministic design procedure, i.e. the characteristic value modified by the resistance factor or load factor, whichever is applicable</td>
</tr>
<tr>
<td>driving voltage</td>
<td>the difference between the closed circuit anode potential and protection potential</td>
</tr>
<tr>
<td>effective clearance</td>
<td>a horizontal distance, which reflects the ability of the free-fall lifeboat to move away from the facility after a free-fall launch without using its engine</td>
</tr>
<tr>
<td>Term</td>
<td>Definitions</td>
</tr>
<tr>
<td>------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>empty lifeboat</td>
<td>lifeboat with the weight of three persons&lt;br&gt;The weight of three persons does not have to be the physical weight of three persons, but can be compensating weights, such as the weight of sandbags.</td>
</tr>
<tr>
<td>environmental state</td>
<td>short-term condition of typically 10 minutes, 1 hour or 3 hours duration during which the intensities of environmental processes such as wave and wind processes can be assumed to be constant, i.e. the processes themselves are stationary</td>
</tr>
<tr>
<td>evacuation system</td>
<td>a system for evacuation from a host facility by means of a free-fall lifeboat</td>
</tr>
<tr>
<td>expected loads and response</td>
<td>the expected load and response history for a specified time period, taking into account the number of load cycles and resulting load levels and response for each cycle</td>
</tr>
<tr>
<td>failure probability</td>
<td>probability of failure or probability of malperformance, e.g. probability of a load exceeding the capacity</td>
</tr>
<tr>
<td>fatigue</td>
<td>degradation of the material caused by cyclic loading</td>
</tr>
<tr>
<td>fatigue critical</td>
<td>structure with a predicted fatigue life near to the design fatigue life</td>
</tr>
<tr>
<td>fatigue limit states (FLS)</td>
<td>fatigue crack growth and associated failure of structural details due to stress concentration and damage accumulation under the action of repeated loading</td>
</tr>
<tr>
<td>free-fall acceleration</td>
<td>rate of change of velocity experienced by the occupants during the launch of a free-fall lifeboat</td>
</tr>
<tr>
<td>free-fall height</td>
<td>the launch height, measured vertically from the mean water level (MWL) to the lowest point on the lifeboat when the lifeboat is in the launch position on a skid or in a davit on the host facility</td>
</tr>
<tr>
<td>free-fall lifeboat</td>
<td>lifeboat which is launched by a free fall from some height above the sea level&lt;br&gt;Free-fall lifeboats are usually used for the emergency evacuation of personnel from offshore facilities and ships.</td>
</tr>
<tr>
<td>fully loaded lifeboat</td>
<td>lifeboat with the weight of the full complement of occupants</td>
</tr>
<tr>
<td>guidance note</td>
<td>information in the standard in order to enhance the understanding of the requirements</td>
</tr>
<tr>
<td>hang-off system</td>
<td>fall arrest device used to release the lifeboat without dropping it to the sea</td>
</tr>
<tr>
<td>highest astronomical tide</td>
<td>level of high tide when all harmonic components causing the tide are in phase</td>
</tr>
<tr>
<td>hindcast</td>
<td>a method using registered meteorological data to reproduce environmental parameters&lt;br&gt;Mostly used to reproduce wave data and wave parameters.</td>
</tr>
<tr>
<td>host facility</td>
<td>fixed or floating offshore structure on which the lifeboat is permanently located and for which it serves as a means of emergency evacuation</td>
</tr>
<tr>
<td>hybrid III</td>
<td>standard crash test dummy used for frontal impact testing&lt;br&gt;The Hybrid III median male (50th percentile male) is 168 cm tall and has a mass of 77 kg.</td>
</tr>
<tr>
<td>independent organizations</td>
<td>accredited or nationally approved certification bodies</td>
</tr>
<tr>
<td>inspection</td>
<td>activities such as measuring, examining, testing or gauging one or more characteristics of an object or service and comparing the results with specified requirements to determine conformity</td>
</tr>
<tr>
<td>launching ramp angle</td>
<td>the angle between the horizontal and the launch rail of the lifeboat in its launching position with the offshore facility, on which it is used, on an even keel</td>
</tr>
<tr>
<td>launching ramp length</td>
<td>the distance between the stern of the lifeboat and the lower end of the launching ramp</td>
</tr>
<tr>
<td>lifeboat system</td>
<td>a structural system consisting of a lifeboat and its supports in storage and use, including a release unit and skids or davits for launching</td>
</tr>
<tr>
<td>light waterline</td>
<td>the waterline of a vessel without cargo</td>
</tr>
<tr>
<td>limit state</td>
<td>a state beyond which a structure or structural component ceases to fulfil its intended function&lt;br&gt;The following categories of limit states are relevant to structures: ULS = ultimate limit state; FLS = fatigue limit state; ALS = accidental limit state; SLS = serviceability limit state.</td>
</tr>
<tr>
<td>list</td>
<td>sideways tilt, inclination, deviation from the vertical</td>
</tr>
<tr>
<td>load effect</td>
<td>effect of a single design load or combination of loads on the equipment or system, such as stress, strain, deformation, displacement, motion, etc.</td>
</tr>
<tr>
<td>lowest astronomical tide (LAT)</td>
<td>level of low tide when all harmonic components causing the tide are in phase</td>
</tr>
<tr>
<td>lowest mean daily temperature</td>
<td>the lowest value, over the year, of the mean daily temperature for the area in question&lt;br&gt;For seasonally restricted service, the lowest value within the time of operation applies.</td>
</tr>
<tr>
<td>Term</td>
<td>Definitions</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>lowest waterline</td>
<td>typical light ballast waterline for ships, transit waterline or inspection waterline for other types of units</td>
</tr>
<tr>
<td>mean daily average temperature</td>
<td>the long-term mean value of the daily average temperature for a specific calendar day</td>
</tr>
<tr>
<td></td>
<td>— Mean: Statistical mean based on a number of years of observations.</td>
</tr>
<tr>
<td></td>
<td>— Average: Average during one day and night (24 hours)</td>
</tr>
<tr>
<td>mean</td>
<td>statistical mean over the observation period</td>
</tr>
<tr>
<td>mean water level (MWL)</td>
<td>mean still water level, defined as the mean level between the highest astronomical tide and lowest astronomical tide</td>
</tr>
<tr>
<td>mean zero-upcrossing period</td>
<td>average period between two consecutive zero-upcrossings of ocean waves in a sea state</td>
</tr>
<tr>
<td>means of launch testing by simulation</td>
<td>a system for testing the release mechanism of the primary means of launching without a free fall</td>
</tr>
<tr>
<td>means of retrieval</td>
<td>a lifting appliance designed to retrieve the lifeboat from the sea to its stowed position on the host facility</td>
</tr>
<tr>
<td>metocean</td>
<td>abbreviation of meteorological and oceanographic</td>
</tr>
<tr>
<td>nondestructive testing (NDT)</td>
<td>structural tests and inspection of welds by visual inspection, radiographic testing, ultrasonic testing, magnetic particle testing, penetrant testing and other nondestructive methods for revealing defects and irregularities.</td>
</tr>
<tr>
<td>offshore standard</td>
<td>DNV GL offshore standards are documents which present the principles and technical requirements for the design of offshore structures</td>
</tr>
<tr>
<td></td>
<td>The standards are offered as DNV GL’s interpretation of engineering practice for general use by the offshore industry in order to achieve safe structures.</td>
</tr>
<tr>
<td>omnidirectional</td>
<td>wind or waves acting in all directions</td>
</tr>
<tr>
<td>partial safety factor method</td>
<td>design method where uncertainties in loads are represented by a load factor and uncertainties in strengths are represented by a material factor</td>
</tr>
<tr>
<td>pilot</td>
<td>the person designated to steer the lifeboat, also referred to as the helmsman</td>
</tr>
<tr>
<td>potential</td>
<td>the voltage between a submerged metal surface and a reference electrode</td>
</tr>
<tr>
<td>primary means of launching</td>
<td>the main lifeboat launching system, normally based on gravity free fall or skidding combined with free fall</td>
</tr>
<tr>
<td>purchaser</td>
<td>the owner or another party acting on its behalf that is responsible for procuring materials, components or services intended for the design, construction or modification of a structure</td>
</tr>
<tr>
<td>qualification</td>
<td>confirmation by examination and the provision of evidence that a piece of technology meets the specified requirements for the intended use</td>
</tr>
<tr>
<td>recommended practice (RP)</td>
<td>the recommended practice publications cover proven technology and solutions that have been found by DNV GL to represent good practice, and which represent one alternative way to satisfy the requirements stipulated in the DNV Offshore Standards or other codes and standards cited by DNV GL</td>
</tr>
<tr>
<td>redundancy</td>
<td>the ability of a component or system to maintain or restore its function when the failure of a member or connection has occurred</td>
</tr>
<tr>
<td></td>
<td>Redundancy can be achieved, for instance, by strengthening or introducing alternative load paths.</td>
</tr>
<tr>
<td>reference electrode</td>
<td>electrode with a stable open-circuit potential used as a reference for potential measurements</td>
</tr>
<tr>
<td>refraction</td>
<td>process by which wave energy is redistributed as a result of changes in the wave propagation velocity caused by variations in the water depth</td>
</tr>
<tr>
<td>reliability</td>
<td>the ability of a component or system to perform its required function without failure during a specified time interval</td>
</tr>
<tr>
<td>requalification</td>
<td>term used for an evaluation of the fitness of a structure following an event which has exposed the structure to significant loading in order to make sure that all the assumptions made in the original design of the structure are still valid and have not suffered from the loading experienced during the event</td>
</tr>
<tr>
<td></td>
<td>An example is the requalification of a lifeboat, originally designed according to this standard, after it has been used for an emergency evacuation. The requalification then implies a verification that, after the emergency evacuation, the lifeboat still fulfils the requirements of this standard.</td>
</tr>
<tr>
<td>residual currents</td>
<td>all components of a current other than tidal current</td>
</tr>
<tr>
<td>Term</td>
<td>Definitions</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| RID<sup>3D</sup>                | crash test dummy  
  Originally a rear impact dummy (RID) used to evaluate the risk of whiplash injuries in car crashes. Its predecessor RID<sup>2</sup> has been transformed into a whiplash dummy for rear, front and oblique whiplash evaluations, hence denoted RID<sup>3D</sup>. |
| risk                            | the qualitative or quantitative likelihood of an accidental or unplanned event occurring considered in conjunction with the potential consequences of such a failure  
  In quantitative terms, risk is the quantified probability of a defined failure mode times its quantified consequence. |
| secondary means of launching    | an alternative lifeboat launching system, normally based on gravity lowering or power lowering by a lifting appliance |
| service temperature             | the service temperature is a reference temperature for various structural parts of the lifeboat, used as a criterion for material selection, such as the selection of steel grades |
| serviceability limit states (SLS) | disruption of normal operations due to deterioration or loss of routine functionality  
  The SLS imply deformations in excess of tolerance without exceeding the load-carrying capacity, i.e., they correspond to the tolerance criteria applicable to normal use or durability. Unacceptable deformations and excessive vibrations are typical examples of SLS. |
| shakedown                      | a linear elastic structural behaviour is established after yielding of the material has occurred |
| slamming load                   | impact load with high pressure peaks during the impact between a body and water |
| specified minimum yield strength (SMYS) | the minimum yield strength prescribed by the specification or standard under which the material is purchased |
| specified value                 | minimum or maximum value during the period considered  
  This value may take into account operational requirements, limitations and measures taken such that the required safety level is obtained. |
| splash zone                     | the external region of a unit which is most frequently exposed to wave action |
| submerged zone                  | the part of a unit which is below the splash zone, including buried parts |
| survival condition              | a condition during which a unit may be subjected to the most severe environmental loadings for which the unit is designed  
  Drilling or similar operations may have been discontinued due to the severity of the environmental loadings. The unit may be either afloat or supported on the sea bed, as applicable. |
| target safety level             | a nominal acceptable probability of structural failure |
| temporary conditions            | an operational condition that may be a design condition, for example the mating, transit or installation phases |
| tensile strength                | the minimum stress level where strain hardening is at maximum or at rupture |
| tidal range                     | the distance between the highest and lowest astronomical tide |
| tide                            | regular and predictable movements of the sea generated by astronomical forces |
| transit conditions              | all unit movements from one geographical location to another |
| trim                            | the adjustment of the angle of the lifeboat to water when the lifeboat is in the launch position  
  Also used as a term to describe the angle or position of a floating host facility with respect to the horizontal. |
| ultimate limit states (ULS)     | the collapse of all or part of the structure due to the loss of structural stiffness or exceedance of load-carrying capacity  
  Overturning, capsizing, yielding and buckling are typical examples of ULS. |
| unidirectional                  | wind and/or waves acting in one single direction |
| verification                    | examination to confirm that an activity, a product or a service is in accordance with specified requirements |
| water-entry angle               | the angle between the horizontal and the launch rail of the lifeboat when it first enters the water |
### 1.4 Acronyms, abbreviations and symbols

#### 1.4.1 Acronyms and abbreviations

1.4.1.1 The acronyms and abbreviations shown in Table 1-5 are used in this standard.

**Table 1-5 Acronyms and abbreviations**

<table>
<thead>
<tr>
<th>Short form</th>
<th>In full</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>one-dimensional</td>
</tr>
<tr>
<td>2D</td>
<td>two-dimensional</td>
</tr>
<tr>
<td>3D</td>
<td>three-dimensional</td>
</tr>
<tr>
<td>AIS</td>
<td>abbreviated injury scale</td>
</tr>
<tr>
<td>ALARP</td>
<td>as low as reasonably practicable</td>
</tr>
<tr>
<td>ALS</td>
<td>accidental limit state</td>
</tr>
<tr>
<td>API</td>
<td>American Petroleum Institute</td>
</tr>
<tr>
<td>BEM</td>
<td>boundary element method</td>
</tr>
<tr>
<td>BS</td>
<td>British Standard (published by the British Standard Institute)</td>
</tr>
<tr>
<td>CAR</td>
<td>combined acceleration ratio</td>
</tr>
<tr>
<td>CFD</td>
<td>computational fluid dynamics</td>
</tr>
<tr>
<td>CN</td>
<td>classification notes</td>
</tr>
<tr>
<td>COG</td>
<td>centre of gravity</td>
</tr>
<tr>
<td>CSM</td>
<td>chopped strand mat</td>
</tr>
<tr>
<td>CTOD</td>
<td>crack tip opening displacement</td>
</tr>
<tr>
<td>DAF</td>
<td>dynamic amplification factor</td>
</tr>
<tr>
<td>DCPD</td>
<td>Dicyclopentadiene</td>
</tr>
<tr>
<td>DDF</td>
<td>deep draught floaters</td>
</tr>
<tr>
<td>DFF</td>
<td>design fatigue factor</td>
</tr>
<tr>
<td>DNV</td>
<td>Det Norske Veritas</td>
</tr>
<tr>
<td>DOF</td>
<td>degree of freedom</td>
</tr>
<tr>
<td>EHS</td>
<td>extra high strength</td>
</tr>
<tr>
<td>FEA</td>
<td>finite element analysis</td>
</tr>
<tr>
<td>FEM</td>
<td>finite element method</td>
</tr>
<tr>
<td>FLS</td>
<td>fatigue limit state</td>
</tr>
<tr>
<td>FMECA</td>
<td>failure mode, effect and criticality analysis</td>
</tr>
<tr>
<td>FORM</td>
<td>first order reliability method</td>
</tr>
<tr>
<td>FPF</td>
<td>first ply failure</td>
</tr>
<tr>
<td>FPSO</td>
<td>floating production, storage and offloading vessel</td>
</tr>
<tr>
<td>FRP</td>
<td>fibre reinforced plastics</td>
</tr>
<tr>
<td>GBS</td>
<td>gravity based structure</td>
</tr>
<tr>
<td>GRP</td>
<td>glass fibre reinforced polyester</td>
</tr>
<tr>
<td>HAT</td>
<td>highest astronomical tide</td>
</tr>
<tr>
<td>HAZ</td>
<td>heat-affected zone</td>
</tr>
<tr>
<td>HAZID</td>
<td>hazard identification analysis</td>
</tr>
<tr>
<td>HAZOP</td>
<td>hazard and operability study</td>
</tr>
<tr>
<td>HIC</td>
<td>head injury criterion</td>
</tr>
<tr>
<td>HISC</td>
<td>hydrogen induced stress cracking</td>
</tr>
<tr>
<td>HLL</td>
<td>human load level</td>
</tr>
<tr>
<td>HS</td>
<td>high strength</td>
</tr>
<tr>
<td>IMO</td>
<td>International Maritime Organization</td>
</tr>
<tr>
<td>IP</td>
<td>ingress protection</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>LAT</td>
<td>lowest astronomical tide</td>
</tr>
<tr>
<td>LED</td>
<td>light emitting diode</td>
</tr>
<tr>
<td>LHS</td>
<td>left hand side</td>
</tr>
<tr>
<td>LSA</td>
<td>life saving appliances</td>
</tr>
<tr>
<td>MEKP</td>
<td>methyl ethyl ketone peroxide</td>
</tr>
<tr>
<td>MWL</td>
<td>mean water level</td>
</tr>
</tbody>
</table>
### Table 1-5  Acronyms and abbreviations (Continued)

<table>
<thead>
<tr>
<th>Short form</th>
<th>In full</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>not applicable</td>
</tr>
<tr>
<td>NACE</td>
<td>National Association of Corrosion Engineers</td>
</tr>
<tr>
<td>NAFEMS</td>
<td>National Agency for Finite Element Methods and Standards</td>
</tr>
<tr>
<td>NDT</td>
<td>nondestructive testing</td>
</tr>
<tr>
<td>NOROG</td>
<td>Norwegian Oil and Gas Association (industry association)</td>
</tr>
<tr>
<td>NS</td>
<td>normal strength</td>
</tr>
<tr>
<td>OLF</td>
<td>Oljeindustriens Landsforening (Oil Industry Association/former name of NOROG)</td>
</tr>
<tr>
<td>PER</td>
<td>project external review</td>
</tr>
<tr>
<td>PMHS</td>
<td>post-mortem human subject (cadaver)</td>
</tr>
<tr>
<td>PPM</td>
<td>parts per million</td>
</tr>
<tr>
<td>QA</td>
<td>quality assurance</td>
</tr>
<tr>
<td>QRA</td>
<td>quantitative risk analysis</td>
</tr>
<tr>
<td>RHS</td>
<td>right hand side</td>
</tr>
<tr>
<td>RP</td>
<td>recommended practice</td>
</tr>
<tr>
<td>RPM</td>
<td>revolutions per minute</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers</td>
</tr>
<tr>
<td>SCE</td>
<td>saturated calomel electrode</td>
</tr>
<tr>
<td>SCF</td>
<td>stress concentration factor</td>
</tr>
<tr>
<td>SLS</td>
<td>serviceability limit state</td>
</tr>
<tr>
<td>SMYS</td>
<td>specified minimum yield stress</td>
</tr>
<tr>
<td>SOLAS</td>
<td>safety of life at sea</td>
</tr>
<tr>
<td>SPH</td>
<td>smoothed particle hydrodynamics</td>
</tr>
<tr>
<td>SRB</td>
<td>sulphate reducing bacteria</td>
</tr>
<tr>
<td>SWL</td>
<td>still water level</td>
</tr>
<tr>
<td>TLP</td>
<td>tension leg platform</td>
</tr>
<tr>
<td>ULS</td>
<td>ultimate limit state</td>
</tr>
<tr>
<td>VARTM</td>
<td>vacuum assisted resin transfer moulding</td>
</tr>
<tr>
<td>VHF</td>
<td>very high frequency</td>
</tr>
<tr>
<td>VOF</td>
<td>volume of fluid</td>
</tr>
<tr>
<td>WF</td>
<td>wave frequency</td>
</tr>
<tr>
<td>WR</td>
<td>woven roving</td>
</tr>
<tr>
<td>WSD</td>
<td>working stress design</td>
</tr>
</tbody>
</table>

### 1.4.2  Symbols

#### 1.4.2.1  Latin characters

- \( a_0 \)  connection area
- \( a_s \)  acceleration of launch skid
- \( b \)  full breadth of plate flange
- \( b_{ef} \)  effective plate flange width
- \( c \)  detail shape factor
- \( c \)  wave celerity
- \( d \)  bolt diameter
- \( d \)  water depth
- \( f \)  frequency
- \( f \)  load distribution factor
- \( f_n \)  natural frequency of structure
- \( f_r \)  strength ratio
- \( f_{ub} \)  nominal lowest ultimate tensile strength
- \( f_{ub} \)  ultimate tensile strength of bolt
- \( f_w \)  strength ratio
\( f_y \) specified minimum yield stress  
\( g \) acceleration of gravity  
\( h \) height  
\( h \) water depth  
\( h_0 \) reference depth for wind-generated current  
\( h_l \) launch height  
\( h_{pc} \) vertical distance from the load point to the position of max filling height  
\( k \) wave number  
\( k_m \) bending moment factor  
\( k_{pp} \) fixation parameter for plate  
\( k_{ps} \) fixation parameter for stiffeners  
\( k_c \) correction factor for curvature perpendicular to the stiffeners  
\( k_s \) hole clearance factor  
\( k_t \) shear force factor  
\( l \) stiffener span  
\( l_0 \) distance between points of zero bending moments  
\( \text{mean} \) arithmetic mean of test results  
\( \text{msv} \) manufacturer’s specified minimum value  
\( \text{msmv} \) manufacturer’s specified value  
\( n \) number  
\( p \) pressure  
\( p_d \) design pressure  
\( p_0 \) valve opening pressure  
\( r \) root face  
\( r_c \) radius of curvature  
\( s \) distance between stiffeners  
\( \text{sdev} \) standard deviation of test results  
\( t \) thickness of laminate  
\( t_0 \) net thickness of plate  
\( t_k \) corrosion addition  
\( t_w \) throat thickness  
\( \nu_{\text{tide}0} \) tidal current at still water level  
\( \nu_{\text{wind}0} \) wind-driven current at still water level  
\( z \) vertical distance from still water level, positive upwards  
\( z_0 \) terrain roughness parameter  
\( A \) scale parameter in logarithmic wind speed profile  
\( A_C \) Charnock’s constant  
\( A_C \) wave crest height  
\( A_T \) wave trough depth  
\( A_W \) wave amplitude  
\( C \) weld factor  
\( C_D \) drag coefficient  
\( C_M \) mass coefficient  
\( C_S \) slamming coefficient  
\( C_e \) factor for effective plate flange
D  deformation load
E  modulus of elasticity
E  environmental load
E  luminous emittance
E[ ]  mean value
F  cumulative distribution function
F  force, load
F_d  design load
F_k  characteristic load
F_{pd}  design preloading force in bolt
G  permanent load
H  wave height
H  reference height for wind speed
H_C  wave crest height
H_0  launch height
H_{max}  maximum wave height
H_0  wave height in deep waters
H_S  significant wave height
L  length of lifeboat
L_{go}  sliding distance
L_{ra}  length of guide rail
M  structural mass of lifeboat and occupants
M  moment
M_p  plastic moment resistance
M_y  elastic moment resistance
N  fatigue life, i.e. number of cycles to failure
N_p  number of supported stiffeners on the girder span
N_s  number of stiffeners between considered section and nearest support
P  load
P_{pd}  average design point load from stiffeners
Q  variable functional load
R  radius
R  resistance
R  ratio between minimum stress and maximum stress
R_d  design resistance
R_k  characteristic resistance
S  girder span as if simply supported
S  power spectral density
S_A  response spectral acceleration
S_D  response spectral displacement
S_V  response spectral velocity
S_d  design load effect
S_k  characteristic load effect
S_x  x-projected exposed wind area of the lifeboat
T  wave period
T_P  peak period
T_R  return period
1.4.2.2 Greek characters

- $\alpha$ angle between the stiffener web plane and the plane perpendicular to the plating
- $\alpha$ exponent in power-law model for wind speed profile
- $\alpha$ coefficient in representation of wave loads according to diffraction theory
- $\beta_w$ correlation factor
- $\delta$ deflection
- $\Delta \sigma$ stress range
- $\phi$ resistance factor
- $\gamma$ spectral peak enhancement factor
- $\lambda$ load factor
- $\gamma_M$ material factor
- $\gamma_{MW}$ material factor for welds
- $\eta$ ratio of fatigue utilization, cumulative fatigue damage ratio
- $\kappa$ Von Karman’s constant
- $\lambda$ wavelength
- $\lambda$ reduced slenderness
- $\theta$ rotation angle
- $\mu$ friction coefficient
- $\nu$ Poisson’s ratio
- $\nu$ spectral width parameter
- $\rho$ density
- $\sigma_0$ design stress
- $\sigma_e$ elastic buckling stress
- $\sigma_{yw}$ characteristic yield stress of weld deposit
- $\sigma_{jd}$ equivalent design stress for global in-plane membrane stress
- $\sigma_{pd1}$ design bending stress
- $\sigma_{pd2}$ design bending stress
- $\sigma_d$ standard deviation of wind speed
- $\omega$ angular frequency
- $\xi$ coefficient in representation of wave loads according to diffraction theory
- $\Phi$ cumulative distribution function
- $\Theta$ launch skid angle.
SECTION 2  SAFETY PHILOSOPHY AND DESIGN PRINCIPLES

2.1  Introduction

2.1.1  Objective

2.1.1.1  The purpose of this section is to present the safety philosophy and corresponding design principles applied in this standard.

2.1.2  Application

2.1.2.1  This section applies to all free-fall lifeboats which are to be built in accordance with this standard.

2.2  Safety philosophy

2.2.1  General

2.2.1.1  The integrity of a lifeboat or lifeboat system constructed to this standard is ensured through a safety philosophy that integrates the safety objective and relevant methodologies as illustrated in Figure 2-1.

![Figure 2-1  Safety philosophy structure](image)

2.2.2  Safety objective

2.2.2.1  An overall safety objective shall be established, planned and implemented, covering all phases from conceptual development until decommissioning.

Guidance note:
Most manufacturers, owners and operators have a policy regarding human aspects, environmental issues and financial issues. Such policies are typically formulated on a general level, but might be supplemented by more detailed objectives and requirements within specific areas. These policies, when available, should be used as a basis for defining the safety objective for a specific lifeboat or lifeboat system. They typically include statements such as:
- the impact on the environment shall be reduced to as low as reasonably practicable
- there shall be no serious accidents and no loss of life.

If no policy is available, or if it is difficult to define the safety objective, it is recommended to get started by carrying out a risk analysis. The risk analysis can be used to identify all hazards and their consequences, and can then enable back-extrapolation to define acceptance criteria and areas that need close follow-up.

It is recommended that the overall safety objective be followed up by giving specific measurable requirements.

2.2.3  Systematic review

2.2.3.1  As far as practical, all work associated with the design, construction and operation of a free-fall lifeboat shall be such as to ensure that no single failure will lead to life-threatening situations for any person or to unacceptable damage to the facilities or the environment.
2.2.3.2 A systematic review or analysis shall be carried out for all phases during the design, construction and operation of a lifeboat to identify and evaluate the consequences of single failures and series of failures in the lifeboat or lifeboat system, such that necessary remedial measures can be taken. The extent of the review or analysis shall reflect the criticality of the lifeboat system, the criticality of planned operations and previous experience with similar lifeboat systems and their operations.

**Guidance note:**
Quantitative risk analysis (QRA) is an accepted methodology for conducting a systematic review. A QRA may provide an estimation of the overall risk to human health and safety, to the environment and to assets. A QRA comprises:
- hazard identification
- assessment of probabilities of failure events
- assessment of accident developments
- consequence and risk assessment.

Other methodologies for identifying potential hazards are a Failure Mode, Effect and Criticality Analysis (FMECA) and Hazard and Operability studies (HAZOP).

A QRA is sensitive to the reliability and possible weaknesses of the data on which it is based. A Project External Review (PER) by people with a wide and deep knowledge of the field of interest may form an alternative to a QRA. Another alternative is to carry out a PER of the QRA.

---end---of---guidance---note---

2.2.4 Safety class methodology

2.2.4.1 In this standard, structural safety is ensured through the use of a safety class methodology. The structure to be designed is assigned a safety class based on the failure consequences. The classification is normally determined by the purpose of the structure. For each safety class, a target safety level can be defined in terms of an annual probability of failure or in terms of a probability of failure per operational event.

2.2.4.2 Three safety classes are defined. Low safety class is used for structures whose failures imply a low risk of personal injuries and pollution, a low risk of economic consequences and negligible risk to human life. Normal safety class is used for structures whose failures imply some risk of personal injuries and significant economic consequences. High safety class is used for structures whose failures imply a great risk of personal injuries or fatalities, significant environmental pollution, major societal losses, or very large economic consequences.

2.2.4.3 Free-fall lifeboats shall be designed to the high safety class.

2.2.5 Target safety

2.2.5.1 The target safety level for the structural design of free-fall lifeboats can be expressed in terms of a nominal target probability of failure per launch event. The nominal target probability of failure for structural design of free-fall lifeboats designed to the high safety class is set at $10^{-5}$ per launch event.

**Guidance note:**
The target probability of failure can be determined by a cost-benefit analysis. In this context, the cost is the cost involved in reinforcing a lifeboat structure whereas the benefit is the number of fatalities averted by this reinforcement of the structure. The principle is to invest in safety by reinforcing the structure until the marginal benefit from the reinforcement becomes too small for additional investments to serve any reasonably practicable purpose. There is proportionality between the reduction in failure probability and the number of fatalities averted by the reinforcement of the structure, such that the target failure probability can be ascertained as the failure probability at the limit between where further investments will serve a purpose and where they will not.

For details of how to determine the target probability of failure, see IMO Guidelines for Formal Safety Assessment.

---end---of---guidance---note---

2.2.5.2 In addition to the safety requirement given in terms of the target probability of failure per launch event, there is a probability of failure requirement for a launch in an extreme sea state. This requirement is based on safety equivalency principles for life-saving appliances and is set at $10^{-2}$. The specified extreme sea state is a three-hour stationary sea state whose significant wave height has a return period of 100 years.

**Guidance note:**
A launch in the specified extreme sea state will be such a rare event that it can be considered an accidental load condition for the lifeboat. Checking that the probability of failure does not exceed $10^{-2}$ in this condition can then be considered a check that the accidental limit state has not been reached.

---end---of---guidance---note---
2.2.5.3 The safety level requirements given in [2.2.5.1] and [2.2.5.2] and the principles behind their derivation apply not only to structural design, but also to design against large accelerations causing human injury in the launch phase and design against collision with the host facility in the subsequent sailing phase.

Guidance note:
The requirement for safety during a launch at an arbitrary point in time, given in [2.2.5.1], governs the design against large accelerations, whereas the requirement for safety during a launch in the 100-year sea state, given in [2.2.5.2], governs the design against collision with the host facility.

---end---of---guidance---note---

2.2.5.4 The target safety level is the same, regardless of which design philosophy is applied.

Guidance note:
The design of a structural component which is based on an assumption of inspections and possible maintenance and repair throughout the design life may benefit from a reduced structural dimension, e.g. a reduced cross-sectional area, compared to that of a design without such an inspection and maintenance plan in order to arrive at the same safety level for the two designs. This refers in particular to designs which are governed by the FLS or SLS. It may be difficult to apply this to designs which are governed by the ultimate limit state (ULS) or accidental limit state (ALS), although this may also be of relevance to such designs, for example for lifeboats which are subject to wear, tear and degradation from wind and sunlight during storage.

---end---of---guidance---note---

2.3 Design principles and design conditions

2.3.1 Methods for structural design

2.3.1.1 The following design principles and design methods for limit state design of free-fall lifeboats are applied in this standard:

— design by the partial safety factor method
— design by direct simulation of the combined load effect of simultaneous load processes
— design assisted by testing
— probability-based design.

2.3.1.2 General design considerations regardless of the design method are also given in [2.3.3.1].

2.3.1.3 This standard is based on the partial safety factor method, which is based on separate assessment of the load effect in the structure due to each applied load process. The standard allows for design by direct simulation of the combined load effect of simultaneously applied load processes, which is useful in cases where it is not feasible to carry out separate assessments of the different individual process-specific load effects.

2.3.1.4 As an alternative or as a supplement to analytical methods, the determination of load effects or resistance may in some cases be based on either testing or observation of the structural performance of models or full-scale structures.

2.3.1.5 Structural reliability analysis methods for direct probability-based design are mainly considered applicable to special case design problems, to calibrate the load and resistance factors to be used in the partial safety factor method and to designs for conditions of which there is limited experience.

2.3.2 Aim of the design

2.3.2.1 Structures and structural elements shall be designed to:

— sustain loads liable to occur during all temporary, operating and damaged conditions if required
— ensure acceptable safety of the structure during its design life
— maintain acceptable safety for personnel and the environment
— have adequate durability against deterioration during the design life of the structure.
2.3.3 Design conditions

2.3.3.1 The design of a structural system, its components and details shall, as far as possible, satisfy the following requirements:

— resistance against relevant mechanical, physical and chemical deterioration
— fabrication and construction comply with relevant, recognized techniques and practice
— inspection, maintenance and repair are possible.

Structures and structural components shall behave in a ductile manner unless the specified purpose requires otherwise.

2.3.3.2 Structural connections are, in general, to be designed with the aim of minimizing stress concentrations and reducing complex stress flow patterns.

2.3.3.3 As far as possible, the transmission of high tensile stresses through the thickness of plates during welding, block assembly and operation shall be avoided. In cases where transmission of high tensile stresses through the thickness occurs, structural material with proven through-thickness properties shall be used.

2.3.3.4 Structural elements in steel structures and aluminium structures may be manufactured according to the requirements given in DNVGL-OS-C401.

2.3.3.5 Structural FRP elements may be manufactured according to [5.8].

2.4 Limit states

2.4.1 General

2.4.1.1 A limit state is a condition beyond which a structure or structural component will no longer satisfy the design requirements.

2.4.1.2 The following limit states are considered in this standard:

*Ultimate limit states (ULS)* correspond to the maximum load-carrying resistance.

*Fatigue limit states (FLS)* correspond to failure due to the effect of cyclic loading.

*Accidental limit states (ALS)* correspond to (1) the maximum load-carrying resistance for (rare) accidental loads or (2) the post-accident integrity of damaged structures.

*Serviceability limit states (SLS)* correspond to tolerance criteria applicable to the intended use or durability.

2.4.1.3 Examples of limit states within each category:

**ULS**

— loss of structural resistance (excessive yielding and buckling)
— failure of components due to brittle fracture
— loss of static equilibrium of the structure, or of a part of the structure, considered as a rigid body, e.g. overturning or capsizing
— failure of critical components of the structure caused by exceeding the ultimate resistance (which in some cases is reduced due to repetitive loading) or the ultimate deformation of the components
— excessive deformations caused by ultimate loads
— transformation of the structure into a mechanism (collapse or excessive deformation).

**FLS**

— cumulative damage due to repeated loads.

**ALS**

— structural damage caused by accidental loads (ALS type 1)
— ultimate resistance of damaged structures (ALS type 2)
— loss of structural integrity after local damage or flooding (ALS type 2).
SLS
— excessive vibrations producing discomfort or affecting non-structural components
— deformations that exceed the limitation of equipment (induced by load and/or temperature)
— deflections that may alter the effect of the acting forces or deformations that may change the
distribution of loads between supported rigid objects and the supporting structure unless these are
explicitly accounted for in the ULS check.

Guidance note:
For conventional offshore structures, excessive motions and excessive deformations are usually referred to as serviceability limit
states (SLS). However, for free-fall lifeboats, excessive motions and excessive deformations can both lead to fatalities and therefore
in many cases have to be referred to as ultimate limit states (ULS).

2.5 Design using the partial safety factor method

2.5.1 General

2.5.1.1 The partial safety factor method is a design method by which the achieved safety level is as close
to the target as possible when applying load and resistance factors to characteristic values of the governing
variables and subsequently fulfilling a specified design criterion expressed in terms of these factors and
these characteristic values. The governing variables consist of
— loads acting on the structure or load effects in the structure
— the resistance of the structure or strength of the materials in the structure.

2.5.1.2 The characteristic values of loads and resistance, or of load effects and material strengths, are
chosen as specific quantiles in their respective probability distributions. The requirements for the load and
resistance factors are set such that possible unfavourable realizations of loads and resistance, as well as
their possible simultaneous occurrences, are accounted for to an extent which ensures that a satisfactory
safety level is achieved.

2.5.2 The partial safety factor format

2.5.2.1 The safety level of a structure or structural component is considered to be satisfactory when the
design load effect \( S_d \) does not exceed the design resistance \( R_d \):
\[
S_d \leq R_d
\]
This is the design criterion. The design criterion is also known as the design inequality. The corresponding
equation \( S_d = R_d \) forms the design equation.

Guidance note:
The load effect \( S \) can be any load effect such as an external or internal force, an internal stress in a cross section, or a deformation,
and the resistance \( R \) against \( S \) is the corresponding resistance such as a capacity, yield stress or critical deformation.

2.5.2.2 There are two approaches to establish the design load effect \( S_{di} \) associated with a particular load
\( F_i \):
(1) The design load effect \( S_{di} \) is obtained by multiplying the characteristic load effect \( S_{ki} \) by a specified load
factor \( \gamma_{fi} \)
\[
S_d = \gamma_{fi} S_k
\]
where the characteristic load effect \( S_{ki} \) is determined by a structural analysis of the structure subjected to
the characteristic load \( F_{ki} \).

(2) The design load effect \( S_{di} \) is obtained from a structural analysis of the structure subjected to the design
load \( F_{di} \), where the design load \( F_{di} \) is obtained by multiplying of the characteristic load \( F_{ki} \) by a specified load
factor \( \gamma_{fi} \)
\[
F_d = \gamma_{fi} F_k
\]
Approach (1) shall be used to determine the design load effect when a proper representation of the dynamic response is the prime concern, whereas Approach (2) shall be used if a proper representation of nonlinear material behaviour or geometrical nonlinearity or both are the prime concern.

2.5.2.3 The design load effect $S_d$ is the most unfavourable combined load effect resulting from the simultaneous occurrence of $n$ loads $F_i$, $i = 1,\ldots,n$. It may be expressed as

$$S_d = f(F_1,\ldots,F_n)$$

where $f$ denotes a functional relationship.

According to the partial safety factor format, the design combined load effect $S_d$ resulting from the occurrence of $n$ independent loads $F_i$, $i = 1,\ldots,n$, can be taken as

$$S_d = \sum_{i=1}^{n} S_d(F_i)$$

where $S_d(F_i)$ denotes the design load effect corresponding to the characteristic load $F_{ki}$.

When there is a linear relationship between the load $F_i$ acting on the structure and its associated load effect $S_i$ in the structure, the design combined load effect $S_d$ resulting from the simultaneous occurrence of $n$ loads $F_i$, $i = 1,\ldots,n$, can be achieved as

$$S_d = \sum_{i=1}^{n} \gamma_m S_i$$

When there is a linear relationship between the load $F_i$ and its load effect $S_i$, the characteristic combined load effect $S_k$ resulting from the simultaneous occurrence of $n$ loads $F_i$, $i = 1,\ldots,n$, can be achieved as

$$S_k = \sum_{i=1}^{n} S_{ki}$$

2.5.2.4 Characteristic load effect values $S_{ki}$ are obtained as specific quantiles in the distributions of the respective load effects $S_i$. In the same manner, characteristic load values $F_{ki}$ are obtained as specific quantiles in the distributions of the respective loads $F_i$.

Guidance note:
Which quantiles are specified as characteristic values may depend on which limit state is considered. They may also vary from one specified combination of load effects to another among the load combinations that are specified to be investigated in order to obtain a characteristic combined load effect $S_k$ equal to a particular quantile in the distribution of the true combined load effect $S$.

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2.5.2.5 In this standard, the ULS design is either based on a characteristic combined load effect $S_k$ defined as the 99% quantile in the long-term distribution of the combined peak environmental load effect during a launch at an arbitrary point in time, or on a characteristic load $F_k$ defined as the 99% quantile in the long-term distribution of the combined peak environmental load during a launch at an arbitrary point in time.

Guidance note:
When $n$ load processes occur simultaneously during a launch, the standard specifies more than one set of characteristic load effects ($S_{k1},\ldots,S_{kn}$) to be considered in order for the characteristic combined load effect $S_k$ to come out as close as possible to the 99% quantile. For each specified set ($S_{k1},\ldots,S_{kn}$), the corresponding design combined load effect is determined according to [2.5.2.3]. For use in design, the design combined load effect $S_d$ is selected as the most unfavourable value among the design combined load effects that result for these specified sets of characteristic load effects.

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2.5.2.6 The resistance $R$ against a particular load effect $S$ is, in general, a function of parameters such as geometry, material properties, environment and the load effect itself, the latter through interaction effects such as degradation.

There are two approaches to establishing the design resistance $R_d$ of the structure or structural component:

1. The design resistance $R_d$ is obtained by dividing the characteristic resistance $R_k$ by a specified material factor $\gamma_m$:

$$R_d = \frac{R_k}{\gamma_m}$$
(2) The design resistance $R_d$ is obtained from the design material strength $\sigma_d$ by a capacity analysis

$$R_d = R(\sigma_d)$$

in which $R$ denotes the functional relationship between material strength and resistance and the design material strength $\sigma_d$ is obtained by dividing the characteristic material strength $\sigma_k$ by a material factor $\gamma_m$,

$$\sigma_d = \frac{\sigma_k}{\gamma_m}$$

Which of the two approaches applies depends on the design situation. In this standard, the approach to be applied is specified from case to case.

2.5.2.7 The characteristic resistance $R_k$ is obtained as a specific quantile in the distribution of the resistance. It may be obtained by testing, or it may be calculated from the characteristic values of the parameters that govern the resistance. In the latter case, the functional relationship between the resistance and the governing parameters is applied. Likewise, the characteristic material strength $\sigma_k$ is obtained as a specific quantile in the probability distribution of the material strength and may be obtained by testing.

2.5.2.8 Load factors account for:
- possible unfavourable deviations of the loads from their characteristic values
- the limited probability that different loads exceed their respective characteristic values simultaneously
- uncertainties in the model and analysis used to determine load effects.

2.5.2.9 Material factors account for:
- possible unfavourable deviations in the resistance of materials from the characteristic value
- uncertainties in the model and analysis used to determine resistance
- a possibly lower characteristic resistance of the materials in the structure, as a whole, compared with the characteristic values interpreted from test specimens.

2.5.3 Characteristic load effect

2.5.3.1 For operational design conditions, the characteristic value $S_k$ of the load effect resulting from an applied load combination is defined as follows, depending on the limit state:
- For load combinations relevant for design against the ULS, the characteristic value of the resulting load effect is defined as the 99% quantile in the long-term distribution of the peak value of the combined load effect during a launch at an arbitrary point in time.
- For load combinations relevant for design against the FLS, the characteristic load effect history is defined as the expected load effect history.
- For load combinations relevant for design against the SLS, the characteristic load effect is a specified value, dependent on operational requirements.
- For load combinations relevant for design against the ALS, the characteristic load effect is a specified value, dependent on operational requirements.

Guidance note:
The characteristic value of a load effect is a representative value of the load effect variable. In general, for a load effect variable, the characteristic value is defined as a high but measurable value with a prescribed probability of not being unfavourably exceeded during some reference period.

For a load effect that governs the design of a free-fall lifeboat against the ULS during a launch at an arbitrary point in time, the reference period of interest is the duration of the launch, and the load effect variable of interest is the peak value of the load effect during this reference period.

The characteristic value of the load effect is defined as the value of the load effect whose probability of being exceeded during the launch is 1%. This is recognized as the 99% quantile in the long-term probability distribution of the peak load effect during the launch. This probability distribution results if a repeated number of launches at arbitrary points in time are conducted and the peak load effect is recorded during each launch.

A free-fall lifeboat is only exposed to the loading from wind and waves, which governs its design during the duration of the launch. This is in contrast to a permanent offshore structure, such as the host facility, which is continuously exposed year-round to the loading from wind and waves which governs its design.

Referring to this difference in exposure, using the 99% quantile in the long-term distribution of the peak load effect as the characteristic load effect value for a free-fall lifeboat is consistent with and analogous to using the 99% quantile in the distribution of
the annual maximum load effect as the characteristic load effect value for a permanent offshore structure which is common practice in offshore design codes. This 99% quantile in the distribution of the annual maximum load effect is recognized by its more popular term, the 100-year load effect.

No 100-year load effect can be associated with the launch of a free-fall lifeboat. If the lifeboat had been continuously exposed to environmental loading year-round, a 100-year load effect could have been established in line with the definition of the characteristic load effect in offshore design codes.

The adopted characteristic load effect, defined as the 99% quantile in the long-term distribution of the peak load effect during a launch at an arbitrary point in time, is a smaller load effect value than such a 100-year load effect under continuous exposure would be. The consequence of this difference is that the required load factors to be used with the adopted definition of the characteristic load effect in design are somewhat higher than those commonly required for use with 100-year load effects in offshore design codes.

App.A provides guidance on how to determine the long-term probability distribution of a quantity such as a resulting load effect and how to determine the 99% quantile in this distribution, e.g. when measurements of the quantity are available from tests.

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2.5.3.2 For temporary design conditions, the characteristic value $S_k$ of the load effect resulting from an applied load combination is a specified value, which shall be selected depending on the measures taken to achieve the required safety level. The value shall be specified with due attention to the actual location, the season of the year, the duration of the temporary condition, the weather forecast and the consequences of failure.

Guidance note:
For a free-fall lifeboat, temporary conditions include transportation of the lifeboat to the site and installation of the lifeboat on the host facility. The launch of the lifeboat, however, is referred to as an operational condition and is not to be handled as a temporary condition.

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2.5.3.3 In some cases, the load effect is a deformation. For design against deformations, no particular characteristic deformation is defined. Instead, a design deformation for direct use in the design checks for deformations is defined as the expected deformation conditional on the characteristic loads factored by the load factor, for example determined by calculations in an FEM analysis.

2.5.4 Characteristic resistance

2.5.4.1 For metallic materials, the characteristic resistance is defined as the 5% quantile in the distribution of the resistance in question, e.g. resistance against buckling or resistance against yield.

2.5.4.2 For composite materials, the characteristic resistance is defined as the 2.5% quantile in the distribution of the resistance in question, e.g. resistance against buckling or resistance against rupture.

2.5.5 Load and resistance factors

2.5.5.1 The load and resistance factors for the various limit states are given in Sec.4 and Sec.6.

2.6 Design assisted by testing

2.6.1 General

2.6.1.1 Design by testing or observation of performance shall in general be supported by analytical or numerical design methods.

2.6.1.2 Load effects, structural resistance and resistance against material degradation may be established by testing or observing the actual performance of full-scale lifeboat structures.

2.6.1.3 To the extent that testing is used in the design process, it shall be verifiable.

2.6.2 Full-scale testing and observation of the performance of existing lifeboat structures

2.6.2.1 Full-scale tests and monitoring of existing lifeboat structures may be used to give information about response and load effects. This information can be utilized when calibrating and updating the safety level of the lifeboat structure. The safety level of the lifeboat structure can also be updated when improved methods become available.
Guidance note:
It can be useful to update the safety level of free-fall lifeboats which have been used for emergency evacuation and are to be requalified. Methods for updating the safety level can be found in Classification Notes No. 30.6.

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2.7 Probability-based design

2.7.1 Definition

2.7.1.1 The structural reliability, or structural safety, is defined as the probability that failure will not occur, or that a specified failure criterion will not be met, within a specified period of time.

2.7.2 Structural reliability analysis

2.7.2.1 As an alternative to design using the partial safety factor method specified in this standard, a full probability-based design using a structural reliability analysis may be carried out. This requires a recognized structural reliability method to be used.

2.7.2.2 This subsection gives requirements to be met for structural reliability analyses that are undertaken in order to document compliance with the standard.

2.7.2.3 Acceptable procedures for structural reliability analyses are documented in Classification Notes No. 30.6.

2.7.2.4 Reliability analyses shall be based on Level 3 reliability methods. These methods utilize the probability of failure as a measure of safety and require representation of the probability distributions of all governing load and resistance variables.

2.7.2.5 In this standard, Level 3 reliability methods are mainly considered applicable to:

— calibrate a Level 1 method to account for improved knowledge
— special case design problems
— novel designs for which limited or no experience exists.

Guidance note:
Level 1 methods are deterministic analysis methods that use only one characteristic value to describe each uncertain variable, i.e. the partial safety factor method applied in this standard.

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2.7.2.6 Reliability analysis may be updated by utilizing new information. Wherever such updating indicates that the assumptions upon which the original analysis was based are not valid, and the result of such non-validation is deemed to be essential to safety, the subject’s approval may be revoked.

2.7.2.7 Target reliabilities shall be commensurate with the consequence of failure. The method of establishing such target reliabilities, and the values of the target reliabilities themselves, should be agreed in each separate case. To the extent possible, the minimum target reliabilities shall be based on established cases that are known to have adequate safety, cf. [2.2.4] and [2.2.5].

2.7.2.8 Where well-established cases do not exist, e.g. in the case of novel and unique design solutions; the minimum target reliability values shall be based upon one or more of the following approaches:

— transferable target reliabilities for similar existing design solutions, i.e. acceptable past practice
— internationally recognized codes and standards
— Classification Notes No. 30.6.

2.7.2.9 Suitably competent and qualified personnel shall carry out the structural reliability analysis. Any extension into new areas of application shall be subject to technical verification.
SECTION 3 ENVIRONMENTAL CONDITIONS

3.1 Introduction

3.1.1 General

3.1.1.1 Environmental conditions consist of all site-specific conditions which may influence the design of a lifeboat by governing its loading, its capacity or both.

3.1.1.2 Environmental conditions cover all meteorological and oceanographic conditions at the site. The environmental conditions of most importance for free-fall lifeboats are dealt with in this section.

Guidance note:

The meteorological and oceanographic conditions which may influence the design of a lifeboat and its lifeboat station and release system consist of phenomena such as the wind, waves, current and water level. These phenomena may be mutually dependent and, for the first three of them, the respective directions form part of the conditions that may govern the design. For more detailed information regarding environmental conditions, see DNV-RP-C205.

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3.1.1.3 Wind, waves, current and water level influence the trajectory of a lifeboat and thereby govern the environmental loads on the lifeboat. Wind, rain, snow, hail and ice may all produce stowage loads when the lifeboat is stowed in the lifeboat station between emergency operations. Humidity, salinity and sunlight will not necessarily imply any loading of the lifeboat, but may over time cause degradation of the lifeboat’s material strengths and structural capacity.

3.1.1.4 Environmental conditions, primarily in terms of the wave climate, form the basis for the environmental loads that a lifeboat will experience during a launch. The wave climate is usually represented by the significant wave height $H_S$ and the peak period $T_P$, which can be assumed as constants in short-term sea states of 3-hour or 6-hour durations, and which can be represented by their joint probability distribution in the long term. The joint site-specific long-term distribution of $(H_S, T_P)$ may be needed in order to establish the long-term distributions of the loads on the canopy and hull that govern the lifeboat’s design and to interpret the corresponding characteristic loads from these distributions.

Guidance note:

When a load on the lifeboat is given in terms of the probability distribution of this load conditional on the sea state parameters $(H_S, T_P)$, e.g. as determined from model tests in irregular sea in the laboratory, the joint long-term distribution of $(H_S, T_P)$ is needed to allow integration over all sea states in order to establish the unconditional long-term distribution of the considered load in a launch of the lifeboat at an arbitrary point in time.

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3.1.1.5 Other environmental conditions that may govern the environmental loads that the lifeboat will experience include, but are not limited to, the wind, current and water level. The wind climate is usually represented by the 10-minute mean wind speed $U_{10}$ and the standard deviation $\sigma_U$ of the wind speed. These properties can be assumed as constants in short-term 10-minute periods and can be represented by their joint probability distribution in the long term. The current climate can be represented by a current speed with a long-term probability distribution. The water level consists of a tidal component and storm surge component and can be represented by its long-term probability distribution.

Guidance note:

It may be relevant to use different averaging periods for wind in the free-fall phase and in the sailing phase.

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3.1.1.6 For lifeboats which are launched from a fixed offshore host structure, the trajectory shall be predicted based on the assumption that the water level is located at LAT. If the difference between LAT and HAT is large, two trajectories should be predicted for water levels located at LAT and HAT, respectively.

Guidance note:

The water level, particularly the tidal effects, influences the free-fall height. The water level needs to be accounted for separately if its variation has not been accounted for in establishing the long-term distribution of the load, for example if this long-term distribution has been established based on model tests in irregular sea in the laboratory, where the still water level has been kept constant equal to the MWL.

There may be cases where the water level at HAT could be more critical than at LAT, for example with respect to headway after the free fall.
In assessing the water level and its effects, the effects of possible subsidence of the seabed need to be addressed for a bottom-fixed host facility.

---end of guidance note---

3.2 Wind conditions

3.2.1 Introduction

3.2.1.1 Wind speed varies over time. It also varies depending on the height above the ground or above the sea surface. For these reasons, the averaging time for wind speeds and the reference height must always be specified.

3.2.1.2 A commonly used reference height is \( H = 10 \) m. Commonly used averaging times are 1 minute, 10 minutes and 1 hour.

3.2.1.3 Wind speed averaged over 1 minute is often referred to as the sustained wind speed.

3.2.1.4 For details of representation of wind conditions, see DNV-RP-C205.

3.2.2 Wind parameters

3.2.2.1 The wind climate can be represented by the 10-minute mean wind speed \( U_{10} \) at a height of 10 m and the standard deviation \( \sigma_U \) of the wind speed at a height of 10 m. In the short term, i.e. over a 10-minute period, stationary wind conditions with a constant \( U_{10} \) and constant \( \sigma_U \) can be assumed to prevail. This wind climate representation is not intended to cover wind conditions experienced in tropical storms such as hurricanes, cyclones and typhoons. Nor is it intended to cover wind conditions experienced during small-scale events such as fast-propagating arctic low pressures of limited extension.

Guidance note:
The 10-minute mean wind speed \( U_{10} \) is a measure of the intensity of the wind. The standard deviation \( \sigma_U \) is a measure of the variability of the wind speed about the mean. When special conditions are present, such as when hurricanes, cyclones and typhoons occur, a representation of the wind climate in terms of \( U_{10} \) and \( \sigma_U \) may be insufficient.

---end of guidance note---

3.2.2.2 The instantaneous wind speed at an arbitrary point in time during 10-minute stationary conditions follows a probability distribution whose mean value is \( U_{10} \) and whose standard deviation is \( \sigma_U \).

3.2.2.3 The turbulence intensity is defined as the ratio \( \sigma_U/U_{10} \).

3.2.2.4 The short-term 10-minute stationary wind climate may be represented by a wind spectrum, i.e. the power spectral density \( S(f) \) of the wind speed process. \( S(f) \) is a function of \( U_{10} \) and \( \sigma_U \) and expresses how the energy of the wind speed is distributed between various frequencies.

3.2.3 Wind data

3.2.3.1 Wind speed statistics are to be used as a basis for representing the long-term and short-term wind conditions. Long-term wind conditions typically refer to 10 years or more, while short-term conditions refer to 10 minutes. The 10-minute mean wind speed at 10 m height above the ground or the still water level is to be used as the basic wind parameter to describe the long-term wind climate and the short-term wind speed fluctuations. Empirical statistical data used as a basis for the design must cover a sufficiently long period of time.

Guidance note:
Site-specific wind data measured over sufficiently long periods with minimum or no gaps are to be sought. For design purposes, the wind climate data base should preferably cover a 10-year period or more of continuous data with a time resolution of 6 hours or better.

---end of guidance note---

3.2.3.2 Wind speed data are height-dependent. The mean wind speed at 10 m height is often used as a reference. When wind speed data for heights other than the reference height are not available, the wind speeds for the other heights can be calculated from the wind speeds at the reference height in conjunction with a wind speed profile above the ground or above the still water level.
3.2.3.3 The long-term distributions of \(U_{10}\) and \(\sigma_U\) should preferably be based on statistical data for the same averaging period for the wind speed as the averaging period which is used to determine loads. If an averaging period other than 10 minutes is used to determine loads, the wind data may be converted by applying appropriate gust factors. The short-term distribution of the instantaneous wind speed itself is conditional on \(U_{10}\) and \(\sigma_U\).

Guidance note:
An appropriate gust factor to convert wind statistics from averaging periods other than 10 minutes depends on the frequency location of a spectral gap, when such a gap is present. The application of a fixed gust factor which is independent of the frequency location of a spectral gap can lead to erroneous results. A spectral gap separates large-scale motions from turbulent-scale motions and refers to those spatial and temporal scales that show little variation in wind speed.

The latest insights into wind profiles above water should be considered to convert wind speed data between different reference heights or different averaging periods.

Unless data indicate otherwise, the conversions may be carried out using the expressions given in [3.2.5.4] and [3.2.5.5].

3.2.3.4 The wind velocity climate at the location of the host facility shall be established on the basis of previous measurements at the actual location and adjacent locations, hindcast predictions as well as theoretical models and other meteorological information. If the wind velocity is of significant importance to the design and existing wind data are scarce and uncertain, wind velocity measurements should be carried out at the location in question.

3.2.4 Wind modelling

3.2.4.1 The long-term probability distributions for the wind climate parameters \(U_{10}\) and \(\sigma_U\) that are derived from available data can be represented in terms of either generic distributions or scatter diagrams. An example of a generic distribution representation consists of a Weibull distribution for the arbitrary 10-minute mean wind speed \(U_{10}\) in conjunction with a lognormal distribution of \(\sigma_U\) conditional on \(U_{10}\). A scatter diagram provides the frequency of occurrence of given pairs \((U_{10}, \sigma_U)\) in a given discretization of the \((U_{10}, \sigma_U)\) space.

3.2.4.2 Unless data indicate otherwise, a Weibull distribution can be assumed for the arbitrary 10-minute mean wind speed \(U_{10}\) in a given height \(z\) above the ground or above the sea water level,

\[
F_{U_{10}}(u) = 1 - \exp\left(\frac{-u}{A}\right)^k
\]

in which the scale parameter \(A\) and the shape parameter \(k\) are site- and height-dependent.

Guidance note:
In areas where hurricanes occur, the Weibull distribution as determined from available 10-minute wind speed records may not provide an adequate representation of the upper tail of the true distribution of \(U_{10}\). In such areas, the upper tail of the distribution of \(U_{10}\) needs to be determined on the basis of hurricane data.

3.2.4.3 In areas where hurricanes do not occur, the distribution of the annual maximum 10-minute mean wind speed \(U_{10,\text{max}}\) can be approximated by

\[
F_{U_{10,\text{max}}}(u) = (F_{U_{10}}(u))^N
\]

where \(N = 52\,560\) is the number of stationary 10-minute periods in one year. Note that \(N = 52\,595\) when leap years are taken into account.

Guidance note:
The quoted power-law approximation of the distribution of the annual maximum 10-minute mean wind speed is a good approximation of the upper tail of this distribution. Usually only quantiles in the upper tail of the distribution are of interest, viz. the 98% quantile which defines the 50-year mean wind speed or the 99% quantile which defines the 100-year mean wind speed. The upper tail of the distribution can be well approximated by a Gumbel distribution, whose expression may be more practical to use than the quoted power-law expression.
3.2.4.4 The annual maximum of the 10-minute mean wind speed $U_{10,max}$ can often be assumed to follow a Gumbel distribution,

$$F_{U_{10,max},1 \text{ year}}(u) = \exp(-\exp(-a(u-b)))$$

in which $a$ and $b$ are site- and height-dependent distribution parameters.

**Guidance note:**
Experience shows that in many cases the Gumbel distribution will provide a better representation of the distribution of the square of the annual maximum of the 10-minute mean wind speed than of the distribution of the annual maximum of the mean wind speed itself.

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3.2.4.5 The 10-minute mean wind speed with a return period $T_R$ in units of years is defined as the $(1-1/T_R)$ quantile in the distribution of the annual maximum 10-minute mean wind speed, i.e. it is the 10-minute mean wind speed whose probability of exceedance in one year is $1/T_R$. It is denoted $U_{10,TR}$ and is expressed as

$$U_{10,TR} = F_{U_{10,max},1 \text{ year}}^{-1}(1-\frac{1}{T_R}) ; T_R>1 \text{ year}$$

in which $F_{U_{10,max},1 \text{ year}}$ denotes the cumulative distribution function of the annual maximum of the 10-minute mean wind speed.

**Guidance note:**
The 50-year 10-minute mean wind speed becomes $U_{10,50} = F_{U_{10,max},1 \text{ year}}^{-1}(0.98)$ and the 100-year 10-minute mean wind speed becomes $U_{10,100} = F_{U_{10,max},1 \text{ year}}^{-1}(0.99)$. Note that these values, calculated as specified, are to be considered as central estimates of the respective 10-minute wind speeds when the underlying distribution function $F_{U_{10,max}}$ is determined from limited data and is encumbered with statistical uncertainty.

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3.2.5 Wind speed profiles

3.2.5.1 The wind speed profile represents the variation of the mean wind speed with height above the ground or above the still water level, whichever is applicable. When terrain conditions and atmospheric stability conditions are not complex, the wind speed profile may be represented by an idealized model profile. The most commonly applied wind speed profile models are the logarithmic model, the power law model and the Frye model, which are presented in [3.2.5.2] through [3.2.5.5].

3.2.5.2 A logarithmic wind speed profile may be assumed for neutral atmospheric conditions and can be expressed as

$$U(z) = U(H) \left( \frac{\ln \left( \frac{z}{H} \right)}{\ln \left( \frac{H}{z_0} \right)} + 1 \right)$$

where $U$ is the mean wind speed, $z$ is the height, $H = 10$ m is the reference height, and $z_0$ is a terrain roughness parameter, which is also known as the roughness length. For offshore locations, $z_0$ depends on the wind speed, the upstream distance to land, the water depth and the wave field. For open sea without waves, $z_0 = 0.0001$ m will be a typical value, whereas for open sea with waves, values up to $z = 0.01$ m are seen. DNV-RP-C205 provides further guidance on the terrain roughness parameter.

3.2.5.3 As an alternative to the logarithmic wind speed profile, a power law profile may be assumed

$$u(z) = u(H) \left( \frac{z}{H} \right)^{\alpha}$$

where the exponent $\alpha$ depends on the terrain roughness. Values for the exponent $\alpha$ at offshore locations are typically in the range 0.12 to 0.14.
3.2.5.4 The following expression can be used to calculate the mean wind speed \( U \) with the averaging period \( T \) at height \( z \) above sea level

\[
U(T, z) = U_{10} \cdot \left( 1 + 0.137 \ln \frac{z}{H} - 0.047 \ln \frac{T}{T_{10}} \right)
\]

where \( H = 10 \) m and \( T_{10} = 10 \) minutes, and where \( U_{10} \) is the 10-minute mean wind speed at height \( H \). This expression converts mean wind speeds between different averaging periods. When \( T < T_{10} \), the expression provides the most likely largest mean wind speed over the specified averaging period \( T \), given the original 10-minute averaging period with stationary conditions and the specified 10-minute mean wind speed \( U_{10} \). The conversion does not preserve the return period associated with \( U_{10} \).

3.2.5.5 For offshore locations, the Frøya wind profile model is recommended unless data indicate otherwise. For extreme mean wind speeds corresponding to specified return periods in excess of about 50 years, the Frøya model implies that the following expression can be used to convert the one-hour mean wind speed \( U_0 \) at height \( H \) above sea level to the mean wind speed \( U \) with the averaging period \( T \) at height \( z \) above sea level

\[
U(T, z) = U_e \cdot \left[ \left( 1 + C \cdot \ln \frac{z}{H} \right) \cdot \left( 1 - 0.41 \cdot I_v(z) \cdot \ln \frac{T}{T_e} \right) \right]
\]

where \( H = 10 \) m, \( T_0 = 1 \) hour and \( T < T_0 \), where

\[
C = 5.73 \times 10^{-2} \sqrt{1 + 0.148 U_0}
\]

and

\[
I_v = 0.06 \cdot (1 + 0.043 U_0) \cdot \left( \frac{z}{H} \right)^{0.22}
\]

and where \( U \) will have the same return period as \( U_0 \).

Guidance note:
The Frøya wind speed profile includes a gust factor which allows the conversion of mean wind speeds between different averaging periods.
The Frøya wind speed profile is a special case of the logarithmic wind speed profile. The Frøya wind speed profile is the best documented wind speed profile for offshore locations and maritime conditions.
Over open sea, the coefficient \( C \) may tend to be about 10% smaller than the value that results from the quoted expression. In coastal zones, somewhat higher values for the coefficient \( C \) should be used, viz. 15% higher for \( U_0 = 10 \) m/s and 30% higher for \( U_0 = 40 \) m/s.

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3.2.6 Turbulence

3.2.6.1 The natural variability of the wind speed about the mean wind speed \( U_{10} \) in a 10-minute period is known as turbulence and is characterized by the standard deviation \( \sigma \). For a given value of \( U_{10} \), the standard deviation \( \sigma \) of the wind speed exhibits a natural variability from one 10-minute period to another. Measurements from several locations show that \( \sigma \) conditional on \( U_{10} \) can often be well represented by a lognormal distribution

\[
F_{\sigma|U_{10}}(\sigma) = \Phi\left( \ln \frac{\sigma - b_0}{b_1} \right)
\]

in which \( \Phi() \) denotes the standard Gaussian cumulative distribution function. The coefficients \( b_0 \) and \( b_1 \) are site-dependent coefficients dependent on \( U_{10} \).

3.2.6.2 The coefficient \( b_0 \) can be interpreted as the mean value of \( \ln \sigma \), and \( b_1 \) as the standard deviation of \( \ln \sigma \). The following relationships can be used to calculate the mean value \( E[\sigma] \) and the standard deviation \( D[\sigma] \) of \( \sigma \) from the values of \( b_0 \) and \( b_1 \),

\[
E[\sigma] = \exp(b_0 + \frac{1}{2} b_1^2)
\]

\[
D[\sigma] = E[\sigma] \exp\left( b_1^2 \right) - 1
\]
3.2.6.3 For details about turbulence and turbulence modelling, see DNV-RP-C205.

3.2.7 Wind spectra

3.2.7.1 Short-term stationary wind conditions may be described by a wind spectrum, i.e. the power spectral density of the wind speed. Site-specific spectral densities of the wind speed process can be determined from available measured wind data.

3.2.7.2 When site-specific spectral densities based on measured data are used, the following requirement for the energy content in the high frequency range should be fulfilled unless data indicate otherwise: the spectral density \( S_U(f) \) shall asymptotically approach the following form as the frequency \( f \) in the high frequency range increases

\[
S_U(f) = 0.14 \cdot \sigma_U^2 \left( \frac{L_u}{U_{10}} \right)^{\frac{3}{2}} f^{-\frac{5}{3}}
\]

in which \( L_u \) is the integral length scale of the wind speed process.

3.2.7.3 Unless data indicate otherwise, the spectral density of the wind speed process may be represented by a model spectrum. Several model spectra exist. They generally agree in the high frequency range, whereas large differences exist in the low frequency range. Most available model spectra are calibrated to wind data obtained over land. Only a few are calibrated to wind data obtained over water. Model spectra are often expressed in terms of the integral length scale of the wind speed process. The most commonly used model spectra with length scales are presented in DNV-RP-C205.

Guidance note:
Caution should be exercised when model spectra are used. It is particularly important to be aware that the true integral length scale of the wind speed process may deviate significantly from the integral length scale of the model spectrum.

3.2.7.4 For wind over water, the Frøya model spectral density is recommended

\[
S_w(f) = 320 \cdot \left( \frac{U_0}{10} \right)^{\frac{\theta}{2}} \left( \frac{z}{10} \right)^{0.468} \frac{\left( 1 + \left( \frac{\tilde{f}}{172} \right)^n \right)}{\left( 1 + \left( \frac{f}{172} \right)^n \right)}
\]

where

\[
\tilde{f} = 172 \cdot f \cdot \left( \frac{z}{10} \right)^{0.20} \left( \frac{U_0}{10} \right)^{-0.75}
\]

and \( n = 0.468 \), \( U_0 \) is the 1-hour mean wind speed at 10 m height in units of m/s, and \( z \) is the height above sea level in units of m. The Frøya spectrum was originally developed for neutral conditions over water in the Norwegian Sea. The use of the Frøya spectrum cannot therefore necessarily be recommended in regimes where stability effects are important. A frequency of 1/2400 Hz defines the lower bound for the range of application of the Frøya spectrum. Whenever it is important to estimate the energy in the low-frequency range of the wind spectrum over water, the Frøya spectrum is considerably better than the Davenport, Kaimal and Harris spectra, all of which are based on studies of wind over land, and should therefore be applied in preference to these spectra.
3.3 Wave conditions

3.3.1 Wave parameters

3.3.1.1 The wave climate is represented by the significant wave height $H_S$ and the spectral peak period $T_P$. In the short term, i.e. over a 3-hour or 6-hour period, stationary wave conditions with constant $H_S$ and constant $T_P$ are assumed to prevail.

Guidance note:
The significant wave height $H_S$ is defined as four times the standard deviation of the sea elevation process. The significant wave height is a measure of the intensity of the wave climate as well as of the variability in the arbitrary wave heights.

3.3.1.2 The wave height $H$ of a wave cycle is the difference between the highest crest and the deepest trough between two successive zero-upcrossings of the sea elevation process. The arbitrary wave height $H$ under stationary 3- or 6-hour conditions in the short term follows a probability distribution which is a function of the significant wave height $H_S$.

3.3.1.3 The wave period is defined as the time between two successive zero-upcrossings of the sea elevation process. The arbitrary wave period $T$ under stationary 3- or 6-hour conditions in the short term follows a probability distribution which is a function of $H_S$, $T_P$ and $H$.

3.3.1.4 The wave crest height $H_C$ is the height of the highest crest between two successive zero-upcrossings of the sea elevation process. The wave crest height is measured from the SWL. The arbitrary wave crest height $H_C$ under stationary 3- or 6-hour conditions in the short term follows a probability distribution which is a function of the water depth, the significant wave height $H_S$ and the zero-upcrossing period $T_Z$.

3.3.1.5 The short-term 3- or 6-hour sea state may be represented by a wave spectrum, i.e. the power spectral density function of the sea elevation process, $S(f)$. $S(f)$ is a function of $H_S$ and $T_P$ and expresses how the energy of the sea elevation is distributed between various frequencies.

3.3.2 Wave data

3.3.2.1 Wave statistics are to be used as a basis for representing the long-term and short-term wave conditions. Empirical statistical data used as a basis for the design must cover a sufficiently long period of time.

Guidance note:
Wave data obtained on site are to be preferred over wave data observed at an adjacent location. Measured wave data are to be preferred over visually observed wave data. Continuous records of data are to be preferred over records with gaps. Longer periods of observation are to be preferred over shorter periods.

When no site-specific wave data are available and data from adjacent locations are to be capitalized on instead, such other data shall be properly transformed to account for possible differences due to different water depths and different seabed topographies. Such transformation shall take the effects of shoaling and refraction into account.

A hindcast of wave data may be used to extend the measured time series, or to interpolate to places where measured data have not been collected. If a hindcast is used, the hindcast model shall be calibrated against measured data to ensure that the hindcast results comply with available measured data.

3.3.2.2 The long-term distributions of $H_S$ and $T_P$ should preferably be based on statistical data for the same averaging period for the waves as the averaging period which is used to determine loads. If an averaging period other than 3 or 6 hours is used to determine loads, the wave data may be converted by applying appropriate adjustment factors.

3.3.2.3 The wave climate and wind climate are correlated because waves are usually wind-generated. The correlation between wave data and wind data shall be accounted for in the design.

Guidance note:
Simultaneous observations of wave and wind data in terms of simultaneous values of $H_S$ and $U_{10}$ should be obtained. It is recommended that the directionality of wind and waves is recorded. Extreme waves may not always come from the same direction as extreme winds. This may in particular be the case when the fetch in the direction of the extreme winds is short.
Within a period of stationary wind and wave climates, individual wind speeds and wave heights can be assumed to be independent and uncorrelated.

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3.3.3 Wave modelling

3.3.3.1 Site-specific spectral densities of the sea elevation process can be determined from available wave data.

3.3.3.2 Unless data indicate otherwise, the spectral density of the sea elevation process for a site exposed to wind sea may be represented by the JONSWAP spectrum,

\[ S(f) = \frac{\alpha g^2}{(2\pi)^5} f^{-5} \exp \left( -\frac{5}{4} \left( \frac{f}{f_p} \right)^4 \right) \exp \left( -\alpha \left( \frac{f-f_p}{\sigma f_p} \right)^2 \right) \]

where

- \( f \) = wave frequency, \( \omega = 1/T \)
- \( T \) = wave period
- \( f_p \) = spectral peak frequency, \( f_p = 1/T_p \)
- \( T_p \) = peak period
- \( g \) = acceleration of gravity
- \( \alpha \) = generalized Phillips’ constant
  = \( 5 \cdot (H_s^2 f_p^4/g^2) \cdot (1-0.287 \cdot \ln \gamma) \)
- \( \sigma \) = spectral width parameter; \( \sigma = 0.07 \) for \( f \leq f_p \)
  and \( \sigma = 0.09 \) for \( f > f_p \)
- \( \gamma \) = peak-enhancement factor.

The zero-upcrossing period \( T_z \) depends on the peak period \( T_p \) through the following approximate relationship,

\[ T_z = T_p \sqrt{\frac{5 + \gamma}{11 + \gamma}} \]

The peak-enhancement factor is

\[ \gamma = \begin{cases} 
5 & \text{for } \frac{T_p}{\sqrt{H_s}} \leq 3.6 \\
\exp(5.75 - 1.15 \frac{T_p}{\sqrt{H_s}}) & \text{for } 3.6 < \frac{T_p}{\sqrt{H_s}} \leq 5 \\
1 & \text{for } 5 < \frac{T_p}{\sqrt{H_s}} 
\end{cases} \]

where \( T_p \) is in seconds and \( H_s \) is in metres.

When \( \gamma = 1 \), the JONSWAP spectrum reduces to the Pierson-Moskowitz spectrum.

For sites exposed to both wind sea and swell, a two-peaked spectral density shall be used as described in DNV-RP-C205.

3.3.3.3 The long-term probability distributions for the wave climate parameters \( H_s \) and \( T_p \) that are interpreted from available data can be represented in terms of either generic distributions or scatter diagrams. A typical generic distribution representation consists of a Weibull distribution for the significant
wave height $H_S$ in conjunction with a lognormal distribution of $T_P$ conditional on $H_S$. A scatter diagram gives the frequency of occurrence of given pairs $(H_S,T_P)$ in a given discretization of the $(H_S,T_P)$ space.

3.3.3.4 Unless data indicate otherwise, a Weibull distribution can be assumed for the significant wave height,

$$F_{H_S}(h) = 1 - \exp\left(-\frac{h - c}{\alpha}\right)$$

**Guidance note:**
The quoted Weibull distribution is recognized as the long-term distribution of the significant wave height and represents the distribution of the significant wave height at an arbitrary point in time.

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3.3.3.5 When $F_{H_S}(h)$ denotes the distribution of the significant wave height in an arbitrary t-hour sea state, the distribution of the annual maximum significant wave height $H_{S\text{max}}$ can be taken as

$$F_{H_{S\text{max}}.1\text{ year}}(h) = (F_{H_s}(h))^N$$

where $N$ is the number of t-hour sea states in one year. For $t = 3$ hours, $N = 2920$.

**Guidance note:**
The quoted power-law approximation to the distribution of the annual maximum significant wave height is a good approximation to the upper tail of this distribution. Usually only quantiles in the upper tail of the distribution are of interest, in particular the 99% quantile which defines the 100-year significant wave height. The upper tail of the distribution can be well approximated by a Gumbel distribution, whose expression is more operational than the quoted power-law expression.

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3.3.3.6 The significant wave height with a return period $T_R$ in units of years is defined as the $(1-1/T_R)$ quantile in the distribution of the annual maximum significant wave height, i.e. it is the significant wave height whose probability of exceedance in one year is $1/T_R$. It is denoted $H_{S,T_R}$ and is found by solving

$$F_{H_{S\text{max}}.1\text{ year}}(H_{S,T_R}) = 1 - \frac{1}{T_R}; \quad T_R > 1 \text{ year}$$

The significant wave height with a return period of one year is defined as the mode of the distribution function of the annual maximum of the significant wave height, i.e.

$$F_{H_{S\text{max}}.1\text{ year}}(H_{S,1\text{ year}}) = 0.368$$

**Guidance note:**
For the 50-year significant wave height $1-1/T_R = 0.98$ and for the 100-year significant wave height $1-1/T_R = 0.99$. Note that the resulting values for significant wave heights with specified return periods, calculated as specified, are to be considered as central estimates of the respective significant wave heights when the underlying distribution function $F_{H_{S\text{max}}}$ is determined from limited data and is encumbered with statistical uncertainty.

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3.3.3.7 In deep waters, the short-term probability distribution of the arbitrary wave height $H$ can be assumed to follow a Rayleigh distribution when the significant wave height $H_S$ is given,

$$F_{H|H_S}(h) = 1 - \exp\left(-\frac{2h^2}{(1-\nu^2)H_S^2}\right)$$

where $F_{H|H_S}$ denotes the cumulative distribution function and $\nu$ is a spectral width parameter whose value is $\nu = 0.0$ for a narrow-banded sea elevation process and $\nu = 0.37$ when the peak-enhancement factor is $\gamma = 3.3$. For further details, see DNV-RP-C205, 3.5.9.2.

The maximum wave height $H_{\text{max}}$ in a 3-hour sea state characterized by a significant wave height $H_S$ can be calculated as a constant factor times $H_S$.

**Guidance note:**
The maximum wave height in a sea state can be estimated by the mean of the highest wave height in the record of waves that occur during the sea state, or by the most probable highest wave height in the record. The most probable highest wave height is also known as the mode of the highest wave height. Both of these estimates for the maximum wave height in a sea state depend on the number of waves, $N$, in the record. $N$ can be defined as the ratio between the duration $T_S$ of the sea state and the mean zero-upcrossing.
period $T_Z$ of the waves. For a narrow-banded sea elevation process, the appropriate expression for the mean of the highest wave height $H_{\text{max}}$ reads

$$H_{\text{max,mean}} = \left( \frac{1}{\sqrt{2\ln N}} + \frac{0.2886}{\sqrt{2\ln N}} \right) H_S,$$

while the expression for the mode of the highest wave height reads

$$H_{\text{max,mode}} = \left( \frac{1}{\sqrt{2\ln N}} \right) H_S.$$

For a sea state of duration $T_S = 3$ hours and a mean zero-upcrossing period $T_Z$ of about 10.8 sec, $N = 1\ 000$ results. For this example, the mean of the highest wave height becomes $H_{\text{max}} \approx 1.94H_S$, while the mode of the highest wave height becomes $H_{\text{max}} \approx 1.86H_S$.

For shorter mean zero-upcrossing periods than the assumed 10.8 sec, $N$ becomes larger, as does the factor on $H_S$. Table 3-1 gives the ratio $H_{\text{max}}/H_S$ for various values of $N$.

### Table 3-1 Ratio for deep water waves in a narrow-banded sea elevation process

<table>
<thead>
<tr>
<th>No. of waves $N = T_S/T_Z$</th>
<th>Ratio $H_{\text{max}}/H_S$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mode</td>
</tr>
<tr>
<td>------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>500</td>
<td>1.763</td>
</tr>
<tr>
<td>1 000</td>
<td>1.858</td>
</tr>
<tr>
<td>1 500</td>
<td>1.912</td>
</tr>
<tr>
<td>2 000</td>
<td>1.949</td>
</tr>
<tr>
<td>2 500</td>
<td>1.978</td>
</tr>
<tr>
<td>5 000</td>
<td>2.064</td>
</tr>
</tbody>
</table>

Other ratios than those quoted in Table 3-1 apply to waves in shallow waters and in cases where the sea elevation process is not narrow-banded.

It is common to base the estimation of $H_{\text{max}}$ on the results for the mode rather than on the results for the mean. Table 3-1 is valid for $H_S/d < 0.2$, where $d$ denotes water depth.

### 3.3.3.8 The long-term probability distribution of the arbitrary wave height $H$ can be found by integration over all significant wave heights

$$F_{H}(h) = \frac{1}{F_{H_S}} \int_{h_S}^{h} \int v_s(h_s,t) \cdot F_{H|H_STP}(h) \cdot F_{TP}(h_s,t) dt dh_s,$$

where

$$v_s = \int_{h_S}^{h} v_s(h_s,t) \cdot F_{TP}(h_s,t) dt dh_s.$$

in which $F_{H|H_STP}(h)$ is the joint probability density of the significant wave height $H_S$ and the peak period $T_P$ and $v_s(h_s,t)$ is the zero-upcrossing rate of the sea elevation process for a given combination of $H_S$ and $T_P$. $F_{H|H_STP}(h)$ denotes the short-term cumulative distribution function for the wave height $H$ conditional on $H_S$ and $T_P$.

### 3.3.3.9 When $F_{H}(h)$ denotes the distribution of the arbitrary wave height $H$, the distribution of the annual maximum wave height $H_{\text{max}}$ can be taken as

$$F_{H_{\text{max,1 year}}}(h) = (F_{H}(h))^{N_W},$$

where $N_W$ is the number of wave heights in one year.

### 3.3.3.10 The wave crest height $H_C$ can roughly be assumed to be 0.65 times the associated arbitrary wave height $H$. For more detailed modelling of wave crest heights, see DNV-RP-C205.

### 3.3.3.11 The wave height with a return period $T_R$ in units of years is defined as the $(1-1/T_R)$ quantile in
the distribution of the annual maximum wave height, i.e. it is the wave height whose probability of exceedance in one year is 1/TR. It is denoted HTR and is found by solving

\[ F_{H_{\text{max}}, \text{1 year}}(H_{TR}) = 1 - \frac{1}{TR}; \quad TR > 1 \text{ year} \]

The wave height with a return period of one year is defined as the mode of the distribution function of the annual maximum of the wave height, i.e.

\[ F_{H_{\text{max}}, \text{1 year}}(H_{1 \text{ year}}) = 0.368 \]

Guidance note:
For the 50-year wave height, 1−1/TR = 0.98 and for the 100-year wave height 1−1/TR = 0.99. Note that the resulting values for individual wave heights with specified return periods, calculated as specified, are to be considered as central estimates of the respective wave heights when the underlying distribution function \( F_{H_{\text{max}}} \) is determined from limited data and is encumbered with statistical uncertainty.

Note also that the 100-year wave height H100 is always greater than the mode of the maximum wave height \( H_{\text{max}} \) in the 3-hour sea state whose return period is 100 years and whose significant wave height is denoted \( H_{S,100} \). This implies that, in deep waters, \( H_{100} \) will be greater than \( H_{\text{max}} = 1.86H_{S,100} \). Values of \( H_{100} \) equal to about 2.0 times \( H_{S,100} \) are not uncommon in deep waters.

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3.3.3.12 The directionality of waves shall be considered when determining wave height distributions and wave heights with specified return periods when such directionality has an impact on the design of a lifeboat.

3.3.4 Wave theories and wave kinematics

3.3.4.1 The kinematics of regular waves may be represented by the analytical or numerical wave theories listed below:

— Linear wave theory (Airy wave theory) for small-amplitude deep water waves.
— Stokes wave theories for steep waves in finite and deep waters.
— Stream Function theory, based on numerical methods and accurately representing the wave kinematics over a broad range of water depths.

The ranges of validity for the different wave theories are outlined in DNV-RP-C205.

3.3.4.2 The wavelength \( \lambda \) in water depth \( d \) is given implicitly by the dispersion relation

\[ \lambda = \frac{g}{2\pi} T^2 \tanh \frac{2\pi d}{\lambda} \]

in which \( T \) is the wave period and \( g \) is the acceleration of gravity. The dispersion relation results from linear wave theory and is not accurate for higher-order Stokes theory and Stream Function theory.

3.3.4.3 For details about wave theories and wave kinematics, see DNV-RP-C205.

3.4 Current

3.4.1 Current parameters

3.4.1.1 The current typically consists of a wind-generated current and a tidal current, as well as a density current when relevant.

3.4.1.2 The current is represented by the wind-generated current velocity \( v_{\text{wind0}} \) at the still water level and the tidal current velocity \( v_{\text{tide0}} \) at the still water level.

3.4.1.3 Currents may have components other than wind-generated currents, tidal currents and density currents. Examples of such current components are

— subsurface currents generated by storm surge and atmospheric pressure variations
— near-shore, wave-induced surf currents running parallel to the coast.
3.4.2  Current data

3.4.2.1  Statistics on currents shall be used as a basis for representing the long-term and short-term current conditions. Empirical statistical data used as a basis for design must cover a sufficiently long period of time.

**Guidance note:**
Current data obtained on site are to be preferred over current data observed at an adjacent location. Measured current data are to be preferred over visually observed current data. Continuous records of data are to be preferred over records with gaps. Longer periods of observation are to be preferred over shorter periods.

---end---of---guidance---note---

3.4.2.2  The variation of current with water depth shall be considered when relevant.

3.4.2.3  In regions where bottom material is likely to erode, special studies of current conditions near the sea bottom may be required.

3.4.3  Current modelling

3.4.3.1  When detailed field measurements are not available, the variation of current velocity with depth may be represented by means of current models given in DNV-RP-C205.

3.4.3.2  Unless data indicate otherwise, the wind-generated current at still water level may be estimated as

\[ v_{\text{wind}0} = k \cdot U_0 \]

where

\[ k = 0.015 \text{ to } 0.03 \]

\[ U_0 = 1\text{-hour mean wind speed at 10 m height} \]

3.5  Water level

3.5.1  Water level parameters

3.5.1.1  The water level consists of a mean water level in conjunction with tidal water and a wind- and pressure-induced storm surge. The tidal range is defined as the range between the highest astronomical tide (HAT) and the lowest astronomical tide (LAT), see Figure 3-1.

\[ \text{MWL} = 0.5 \text{(HAT+LAT)} \]

**Figure 3-1** Definition of water levels when the low still water level is governing (left) and when the high still water level is governing (right)

3.5.2  Water level data

3.5.2.1  Water level statistics shall be used as a basis for representing the long-term and short-term water level conditions. Empirical statistical data used as a basis for design must cover a sufficiently long period of time.
Guidance note:
Water level data obtained on site are to be preferred over water level data observed at an adjacent location. Measured water level data are to be preferred over visually observed water level data. Continuous records of data are to be preferred over records with gaps. Longer periods of observation are to be preferred over shorter periods.
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3.6 Other environmental conditions

3.6.1 Snow and ice accumulation

3.6.1.1 When the lifeboat is to be located and stowed in an area where ice may develop, ice conditions shall be properly considered.

3.6.1.2 Ice accretion from sea spray, fog, snow, rain and air humidity shall be considered wherever relevant. This applies to the lifeboat and its release system and also to the lifeboat station with its skids, hooks and launching arrangements. Consideration of ice accretion shall include consideration of symmetrical and asymmetrical icing scenarios. In the case of floating host facilities, both the intact and damaged stability conditions of the host facility shall be considered. DNVGL-OS-A201 can be applied to the assessment of ice accretion.

3.6.2 Salinity

3.6.2.1 The salinity of seawater shall be addressed with a view to its potential influence with respect to corrosion.

Guidance note:
The salinity of seawater may contribute to a corrosive environment for the lifeboat during stowage.
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3.6.3 Temperature

3.6.3.1 Extreme values of high and low temperatures shall be expressed in terms of the most probable highest and most probable lowest value for the return period in question.

3.6.3.2 To ensure complete representation of the temperature environment, both air and seawater temperatures shall be considered.

3.6.4 Air density

3.6.4.1 Air density shall be addressed since it affects the structural design through wind loading.

3.6.5 Ultraviolet light

3.6.5.1 Ultraviolet light shall be addressed with a view to its potential for material degradation during stowage of the lifeboat.
SECTION 4 LOADS AND LOAD EFFECTS

4.1 Introduction

4.1.1 General

4.1.1.1 This section specifies the loads, load components and load combinations to be considered in the overall strength analysis for the design of lifeboats and lifeboat systems. Requirements for the representation of these loads and their combinations are given. Some of the load cases specified are also relevant to the assessment of accelerations causing human loads. Some of the load cases are relevant to the assessment of sail-away after launch too.

4.1.1.2 Regarding the representation of site-specific sea state wave parameters and the wind and current climate, which form an important basis for predicting hydrodynamic loads, see Sec.3.

4.2 Basis for selecting characteristic loads

4.2.1 General

4.2.1.1 Unless specific exceptions apply, as documented within this standard, characteristic load effects as specified in Table 4-1 shall apply to temporary design conditions, characteristic load effects as specified in Table 4-2 shall apply to operational design conditions, and characteristic load effects as specified in Table 4-3 shall apply to stowage design conditions.

Guidance note:
Temporary design conditions cover design conditions during transport, assembly, maintenance, repair and decommissioning of the lifeboat and lifeboat system.
Operational design conditions cover design conditions during the launch of the lifeboat.
Stowage design conditions cover design conditions during stowage of the lifeboat in the lifeboat station.

4.2.1.2 Wherever environmental and accidental loads might act simultaneously, the characteristic load effects may be determined based on their joint probability distribution.

4.2.1.3 Characteristic values of environmental and accidental loads might act simultaneously, the characteristic load effects may be determined based on their joint probability distribution.

Table 4-1 Basis for selecting characteristic load effects for temporary design conditions

<table>
<thead>
<tr>
<th>Load category</th>
<th>ULS</th>
<th>FLS</th>
<th>ALS</th>
<th>SLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent (G)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable (Q)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental (E)</td>
<td>Specified value</td>
<td>Expected load effect history</td>
<td>Specified value</td>
<td>Specified value</td>
</tr>
<tr>
<td>Accidental (A)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deformation (D)</td>
<td></td>
<td></td>
<td></td>
<td>Expected extreme value</td>
</tr>
</tbody>
</table>
4.2.2 Characteristic loads during lifeboat launches

4.2.2.1 The basis for defining the characteristic value of a particular load associated with the launch of a lifeboat is the peak value of this load during the entire launch operation consisting of the release, freefall, immersion and resurfacing of the lifeboat.

Guidance note:
An example of a load associated with the launch of a lifeboat is the water pressure in a specified position of the canopy, and the peak value of this water pressure during the launch operation is then considered. Another example is the slamming pressure against the hull when the lifeboat impacts the water surface.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

4.2.2.2 For design against the ULS, the characteristic value of a particular load associated with the launch of the lifeboat is defined as the 99% quantile in the long term distribution of the associated peak load during a launch initiated at an arbitrary point in time.

Guidance note:
The lifeboat is in principle to be used in an emergency situation only once at the most. Without limitations on the weather conditions in which the lifeboat can be used, and without correlation between the weather conditions and the launch event, it is the value of the peak load during a launch operation initiated at an arbitrary point in time which is of interest. The peak load during a launch initiated at an arbitrary point in time is represented by the long-term distribution of the peak load.
The long-term distribution of the peak load can be established from the short-term distribution of the peak load conditional on sea state parameters such as the significant wave height $H_S$ and the peak period $T_P$. This requires integration of the short-term distribution over all realizations of the sea state parameters, weighted according to the joint long-term distribution of the sea state parameters. The peak load during a launch in a sea state characterized by a particular set of sea state parameters ($H_S, T_P$) will vary from one launch to another and have a probability distribution, because there will be variability in the height and period of the wave that the lifeboat hits when it enters the water and because the position on the wave where the lifeboat enters will vary. Parameters other than $H_S$ and $T_P$ which may be needed to characterize a sea state when the long-term distribution of the peak load during launch is to be established are the current speed, water level and wind.

The choice of the characteristic value of the peak load as a high quantile in the long-term distribution of the peak load reflects a desire to account for the natural variability in the peak load by using an unfavourable value in the design. It also reflects a desire to capture the loads that are associated with a launch into the most unfavourable water entry point on the profile of the wave that passes when the launch is carried out.

Wave and wind directions are important parameters.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

### 4.2.2.3 For design against the ULS, the characteristic ULS load, defined as the 99% quantile in the long-term distribution of a particular load, shall be estimated for every conceivable condition for the lifeboat and its host structure during the launch. The most unfavourable characteristic load value among those estimated shall be used in design. Conditions to be assumed for design against the ULS include, but are not necessarily limited to,

- fully loaded lifeboat (lifeboat with the weight of the full complement of occupants)
- empty lifeboat (lifeboat with the weight of three persons).

For lifeboats on floating host facilities, additional conditions to be assumed for design against the ULS include

- a launch from a damaged host floater with trim and list.

The damaged condition of the host facility shall be considered as relevant. The trim and list of a floating host facility in a damaged condition depend on the stability of the host facility and are the results of a loss of buoyancy in one or more supporting buoyant compartments. The trim and list of the damaged host facility shall be set at $\pm 17^\circ$ unless other host-facility-specific values are known.

**Guidance note:**

For lifeboats on floating host facilities, the requirement in this clause implies that a characteristic ULS load, as given in Table 4-2, shall be estimated based on the assumption that the host facility has a permanent trim and list of $\pm 17^\circ$ (or a permanent trim and list equal to the host-facility-specific trim and list when applicable) in all emergency evacuation situations. This characteristic ULS load shall be used in the design if it is unfavourable relative to characteristic ULS loads estimated on the basis of other assumptions.

Since only a fraction of the emergency evacuation situations for a floating host facility is associated with trim and list, the requirement to assume trim and list in all situations may seem too conservative. Such conservatism can be circumvented by following a probabilistic design approach as outlined in [2.7] instead of the deterministic design approach based on characteristic loads.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

### 4.2.2.4 Regular design waves with defined critical hit points may be used to derive estimates of characteristic ULS loads. It has to be demonstrated, based on analysis, that this procedure gives load estimates which are not non-conservative estimates of the characteristic load defined as the 99% quantile in the long-term distribution of peak loads during a launch at an arbitrary point in time.

### 4.2.2.5 A classical nonlinear regular wave theory, e.g. Stokes 5th order or Stream Function, can be used to model the design wave. The design wave is characterized by the wave height and wave period, which shall be chosen such as to provide load estimates which are not non-conservative estimates of the sought-after characteristic loads defined as specified in [4.2.2.4].

### 4.2.2.6 For design against the ALS, the characteristic value of a particular load associated with the launch of the lifeboat is defined as the 99% quantile in the short-term distribution of the associated peak load during a launch initiated in a sea state whose significant wave height has a return period of 100 years.

The damaged condition of the host facility shall be considered as relevant. The trim and list of a floating host facility in a damaged condition depend on the stability of the host facility and are the results of a loss of buoyancy in one or more supporting buoyant compartments. The trim and the list of the damaged host facility shall be set at $\pm 17^\circ$ unless other host-facility-specific values are known. This applies to design checks of damaged lifeboat structures against environmental loads as well as to design checks of intact lifeboat structures against accidental loads.
4.2.3 Characteristic loads during lifeboat stowage

4.2.3.1 For design against the ULS, the characteristic value of a particular environmental load is defined as the 99% quantile in the distribution of the annual maximum of the load in question, i.e. the 100-year value of the load.

**Guidance note:**
During stowage of the lifeboat in the lifeboat station on the host facility, the prime environmental loading expected stems from wind. The characteristic wind load is the wind load whose return period is 100 years.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

4.2.3.2 For design against the ALS, the characteristic value of a particular environmental load is defined as the 99.99% quantile in the distribution of the annual maximum of the load in question, i.e. the 10000-year value of the load.

4.3 Permanent loads (G)

4.3.1 General

4.3.1.1 Permanent loads are loads that will not vary in magnitude or position during the period considered. Examples are:
- mass of structure
- mass of permanent ballast and equipment
- external and internal hydrostatic pressure of a permanent nature
- reactions to the above.

4.3.1.2 The characteristic value of a permanent load is defined as the expected value of the load based on accurate data for the structure, the mass of the material and the volume in question.

**Guidance note:**
The expected value of a permanent load may be calculated from the nominal dimensions and the mean values of the material densities.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---
4.4 Variable functional loads (Q)

4.4.1 General

4.4.1.1 Variable functional loads are loads which may vary during the period under consideration and are related to storage and operation of the structure. Examples are:

— weight of occupants and their personal supplies (clothes, survival suits)
— loads from fenders
— loads from variable ballast and equipment
— stored materials, equipment, gas, fluids and fluid pressure.

4.4.1.2 Loads on access platforms and internal structures are used only for the local design of these structures and therefore usually do not appear in any load combination for the design of primary lifeboat structures.

4.4.1.3 The characteristic value of a variable functional load is the maximum (or minimum) specified value, whichever produces the most unfavourable load effects in the structure under consideration.

Guidance note:

For each load or load effect to be considered for the lifeboat structure, the most unfavourable number, weight and distribution of occupants must be assumed when establishing the characteristic load or load effect. Situations may well exist where the highest load or load effect occurs for a partly occupied lifeboat with an uneven distribution of the occupants, e.g. all the occupants in a half-full lifeboat are seated up front. [4.2.2.3] specifies a minimum number of relevant load conditions to be considered.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.4.1.4 The specified value shall be determined on the basis of relevant specifications. An expected load history or load effect history shall be used in the FLS.

4.4.1.5 Unless data indicate otherwise, the mass of an occupant including clothes and survival suit can be set equal to 100 kg.

Guidance note:

For the condition with 100% loaded lifeboat, a low weight of occupants with survival suits rather than a high weight will be conservative with respect to accelerations, whereas a high weight rather than a low weight will be conservative with respect to maximum submersion and possibly also to headway after resurfacing. In general, an assumption of a high weight of occupants is recommended, in particular with a view to the difficulty in satisfying the headway requirements.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.4.2 Tank pressures

4.4.2.1 Requirements for hydrostatic pressures in tanks are given in DNVGL-OS-C101.

4.4.3 Miscellaneous loads

4.4.3.1 Railing shall be designed for a concentrated load of 1.0 kN. The railing shall also be designed for a horizontal line load equal to 0.3 kN/m applied to the top of the railing. The concentrated load and line load need not be applied simultaneously.

4.4.3.2 Ladders shall be designed for a concentrated load of 2.5 kN.

4.5 Environmental loads (E)

4.5.1 General

4.5.1.1 Environmental loads are loads which may vary in magnitude, position and direction during the period under consideration, and which are related to the operations and normal use of the lifeboat. Examples are:

— hydrodynamic loads induced by waves and current, including drag forces, inertia forces and slamming forces
— wind loads
— water level.

4.5.1.2 According to this standard, characteristic environmental loads and load effects are defined as quantiles with specified probabilities of exceedance. The statistical analysis of measured data or simulated data should make use of different statistical methods to evaluate the sensitivity of the result. The validation of distributions with respect to data should be tested by means of recognized methods. The analysis of the data shall be based on the longest possible time period for the relevant area. In the case of short time series, statistical uncertainty shall be accounted for when characteristic values are determined.

4.5.1.3 The environmental loads acting on the lifeboat during the launch can be referred to three motion phases:

— motion in air
— submerged or partially submerged motion phase (trajectory through the water)
— sailing motion phase.

The three motion phases are further dealt with in [4.5.2], [4.5.3] and [4.5.4], respectively, with an emphasis predicting of the trajectory of the lifeboat through air and water.

4.5.2 Trajectory in air

4.5.2.1 The trajectory of the lifeboat through the air during a launch operation governs the environmental loads that the lifeboat structure becomes exposed to during the launch operation.

4.5.2.2 The trajectory in air shall be predicted to form part of the basis for load calculations.

4.5.2.3 A free-fall lifeboat can be launched from a skid (Figure 4-2) or dropped vertically from a hook (Figure 4-5). The launch of the lifeboat from a skid is composed of three phases:

— sliding phase along the launch skid
— constrained rotation phase
— free-fall phase.

In a preliminary design phase for a lifeboat, a simplified two-dimensional analysis can be used to predict the trajectory in air. A mathematical model for such analysis is given in [4.5.2.5] to [4.5.2.10]. For the final design, a full three-dimensional model shall be used for numerical predictions.

4.5.2.4 The sliding phase is the phase when the lifeboat slides along the launch skid. In calm water, the motion of the lifeboat down the launch skid can be taken as purely translational. In waves, the effect of the motion of the launch skid shall be taken into account. In general, the launch skid will have a time-dependent velocity and acceleration during the launch.

4.5.2.5 The main parameters determining the motion during the sliding phase are the launch skid angle \(\theta\), the coefficient of friction \(\mu\) between the launch skid and guide rail on the lifeboat, and the acceleration of the launch skid due to the wave-induced motion of the host structure. A strong head wind may reduce the acceleration during sliding and the resulting translational velocity at the start of the rotation phase.

**Guidance note:**
In the sliding phase, the motion of the lifeboat is governed by the following parameters (Figure 4-2)

- \(M\) = structural mass of lifeboat and occupants
- \(g\) = acceleration of gravity (9.81 m/s\(^2\))
- \(\mu\) = coefficient of friction
- \(\theta\) = launch skid angle
- \(L_{go}\) = sliding distance
- \(L_{ra}\) = length of guide rail
- \(U_w(t)\) = instantaneous wind speed in the launch direction
- \(\rho_a\) = mass density of air
- \(C_{Dx, Dz}\) = wind coefficients in x- and z-directions
- \(S_x, S_z\) = x- and z-projected exposed wind area of the lifeboat
- \(a_s\) = acceleration of launch skid \(a_s = (a_x, a_z)\)
In the sliding and constrained rotation phases, the motion of the lifeboat can be modelled as a three degrees of freedom system, specified by coordinates \((x,z)\) of the centre of gravity (COG) and the rotational angle \(\theta\) of the axis of the lifeboat relative to the horizontal.

The forces acting on the lifeboat during the sliding phase are the gravity force \(Mg\), the reaction force normal to the guide rail \(F_n\) and the friction force parallel to the guide rail \(\mu F_n\) and in the opposite direction of the motion. When the lifeboat is launched in a strong head (or following) wind, the wind drag force shall be taken into account.

The equations of motion in the sliding phase are given by

\[
M\ddot{x} = M\beta_x = F_x (\sin \theta - \mu \cos \theta) + F_{wx}
\]

\[
M\ddot{z} = M\beta_z = F_z (\cos \theta + \mu \sin \theta) - Mg + F_{wz}
\]

where \((\ddot{x}, \ddot{z})\) are the accelerations of COG, \(F_{wx}\) is the instantaneous horizontal component of the wind force given by

\[
F_{wx} = \frac{1}{2} \rho_a C_{Dw} S_x U_w |U_w|
\]

and \(F_{wz}\) is the vertical component of the wind force

\[
F_{wz} = \frac{1}{2} \rho_a C_{Dw} S_z U_w |U_w|
\]

These equations of motions are based on the assumption that a strong wind has an effect on the motion of the lifeboat, \(U_w >> \dot{x}\).

During the sliding phase the lifeboat axis coincides with the direction of the launch skid, \(\theta = \Theta\). For a fixed host structure or in the case of a floating host structure in mild wave conditions, the reaction force is given by

\[
F_n = (Mg - F_{wn}) \cos \Theta - F_{wn} \sin \Theta
\]

Note that for head wind, \(F_{wx} < 0\).

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

Guidance note:

In the case of a wave-generated motion of a floating host structure with acceleration \(a_s = (a_x, a_z)\) of the launch skid, inertia forces \(-Ma_x\) and \(-Ma_z\) should be added to the RHS of the equations of translational motion given above. \(a_x\) is the horizontal acceleration and \(a_z\) is the vertical acceleration.

The reaction force normal to the launch skid is given by

\[
F_n = [M(g + a_x) - F_{wn}] \cos \Theta + (Ma_z - F_{wn}) \sin \Theta
\]

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

Figure 4-2  Launching parameters of a free-fall lifeboat. Sliding phase.
4.5.2.6 The coefficient of friction for the material applied in contact areas between the guide rail on the lifeboat and the launch skid shall be determined by testing. The coefficient of friction is sensitive to surface wetting, material combination, surface finish and contaminations. The possible change in the coefficient of friction due to such effects and the degradation of material over time shall be assessed. It should be noted that the sliding frictional resistance is normally different from the static frictional resistance.

Guidance note:
The coefficient of friction may typically vary from $\mu = 0.05$ for lubricated surfaces to $\mu = 0.40$ for dry surfaces. Nylon blocks may be used for contact between the guide rail and launch skid. The coefficient of friction for the relative motion between one dry nylon surface and another may vary between 0.15 and 0.25.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

4.5.2.7 If the launch skid is in a rotated position during the launch due to extensive heel or list of the platform, the effective coefficient of friction may be different to that in the designed position, due to contact between different materials and change in normal force. The effect of this change of coefficient of friction should be considered.

4.5.2.8 The pure sliding phase ends when the lifeboat's centre of gravity (COG) passes the lower end (point $O$ in Figure 4-2) of the launch skid, and the lifeboat begins to rotate. In the constrained rotation phase, the lifeboat's rate of rotation increases until the lifeboat is no longer in contact with the launch skid. Wind can have a significant effect during the constrained rotation phase, inducing both pitch and yaw moments on the lifeboat.

Guidance note:
In the rotation phase, the motion of the lifeboat in a vertical plane (2D motion) is governed by the following additional parameters (Figure 4-3),

\[ I = Mr^2 = \text{rotational pitch moment of inertia of lifeboat including occupants} \]
\[ r = \text{radius of gyration of lifeboat} \]
\[ h = \text{distance from guide rail to centre of gravity} \]
\[ d = \text{distance along guide rail from end of launch skid to centre of gravity} \]
\[ M_{w}(t) = \text{instantaneous wind induced moment} \]

It should be noted that the mass of the lifeboat as well as the radius of gyration depends on the loading condition (the number of occupants on board and positions of the occupants).

The rotation of the lifeboat is determined by a moment from a force couple produced by the weight of the body and the reaction force on the guide rail. The governing equations for the translational motion of the centre of gravity are the same as for the sliding phase given in [4.5.2.5]. For a launch in a strong head (or following) wind, the resulting moment due to wind drag should be taken into account. The equation of motion for the rotation of the lifeboat during this phase is

\[ I \ddot{\theta} = F_n \left[ x \cos \theta - z \sin \theta + \mu h \right] + M_{w}(t) \]

where $F_n$ is the reaction force normal to the guide rail and $M_{w}(t)$ is the instantaneous wind induced pitch moment. During rotation, the following geometrical restraint condition holds

\[ x \sin \theta + z \cos \theta = h \]

where $h$ is the distance between the lower surface of the guide rail and the centre of gravity (COG) of the boat.

During rotation of the lifeboat, the normal force $F_n$ changes with time. An explicit expression for $F_n$ can be obtained by differentiating the restraint condition above and eliminating the translational and rotational accelerations from the equations of motion,

\[ F_n = \frac{P(x, z, \theta; \dot{x}, \dot{z}, \dot{\theta})}{R(x, z, \theta)} \]

where

\[ P(x, z, \theta; \dot{x}, \dot{z}, \dot{\theta}) = M [g \cos \theta - (F_n / M) \sin \theta] - M [M_{w} d / I + 2(\dot{x} \cos \theta - \dot{z} \sin \theta) \dot{\theta} - h \dot{\theta}^2] \]

\[ R(x, z, \theta) = I + Md (d + \mu h) \]

The distance along the guide rail from the end of the launch skid to the centre of gravity is given by

\[ d = d(x, z, \theta) = x \cos \theta - z \sin \theta \]

At the start of the rotation phase, $d = -\mu h$, $\dot{\theta} = 0$, $M_{w} d / I$ is very small and can be neglected. Hence, the expression for the reaction force is reduced to the expression for the reaction force in the sliding phase given in [4.5.2.5].
The rotation phase continues as long as the normal reaction force is nonzero ($F_n > 0$). The duration of the rotation at the end of the launch skid is determined by the length of the guide rail, $L_{ra}$. The selection of a very small $L_{ra}$ results in a negligible rotation at the edge of the skid.

In a full three-dimensional analysis, the horizontal wind-velocity component normal to the skid should be included in order to capture a possible yaw rotation of the lifeboat around a vertical axis during the constrained rotation phase.

--- Guidance note: ---

In the case of a wave-generated motion of a floating host structure with acceleration $a_s = (a_x, a_z)$ of the launch skid, $g \cos \theta$ shall be replaced by $(g+a_z)\cos \theta + a_x \sin \theta$ in the expression for the reaction force $F_n$ normal to the launch skid.

--- end-of-guidance-note ---

Figure 4-3  Launching parameters of a free-fall lifeboat. Constrained rotation phase

4.5.2.9 The free-fall phase starts when the lifeboat is no longer in contact with the launch skid ($F_n = 0$) and ends when the bow first makes contact with the water surface. During the free fall, the forces acting on the lifeboat are the gravity force, wind force and moment, taking into account the relative motion between the lifeboat and air. Wind coefficients for the six degrees of freedom are needed to calculate the wind forces and moments. See Figure 4-4.

--- Guidance note: ---

The equations of motion during the free-fall phase are

$$
\begin{align*}
\dot{M}x &= F_{wx}(t) \\
\dot{M}z &= -Mg + F_{wz}(t) \\
\dot{I}\dot{\theta} &= M_{wz}(t)
\end{align*}
$$

where $F_{wx}(t)$ and $F_{wz}(t)$ are the instantaneous wind forces in the x- and z-direction respectively and $M_{wz}(t)$ is the instantaneous wind moment. The wind force and moment will depend on the direction of the wind relative to the instantaneous orientation of the lifeboat. It is a prerequisite that, for a given lifeboat geometry, the wind coefficients are pre-calculated by validated computational fluid dynamics (CFD) simulations or determined in wind tunnel tests. For small to moderate wind speeds, the lifeboat will rotate during the free fall with a rate of rotation approximately equal to the rate of rotation $\omega_0$ when the boat leaves the edge of the launch skid. The change of rotation angle during the free fall is given by $\Delta \theta = \omega_0 t$, where $t$ is the duration of the free fall.

--- end-of-guidance-note ---

4.5.2.10 The possibility of enhanced wind velocity in the launch area due to the geometric constrictions of the host structure shall be considered. Wind tunnel tests or CFD analyses should be carried out to quantify this effect. A reduction in wind velocity due to possible shielding effects may be considered. Such reduction shall be documented by wind tunnel tests or CFD analyses. It should be noted that wind velocity may also be enhanced on the lee-side of the host structure depending on the host geometry and wind direction.
Figure 4-4 Launching parameters of a free-fall lifeboat. Free-fall phase

Guidance note:
The complete trajectory of the lifeboat in air is found by numerically integrating the equations of motions for $x(t)$, $z(t)$ and $\theta(t)$ in each of the three phases as given in [4.5.2.5], [4.5.2.8] and [4.5.2.9]. The change from one phase to another is determined by $d + \mu \theta = 0$ when going from pure sliding to the constrained rotation phase, and $F_n = 0$ when going from the constrained rotation phase to the free-fall phase.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Figure 4-5 Free-fall lifeboat launched from hook

4.5.2.11 When the lifeboat is launched from a floating host structure, the wave-induced motion of the host structure shall be taken into account when calculating the lifeboat trajectory through air after launching. The wave-induced acceleration $a_s$ of the launch skid or hook shall be included in the equations of motion for the lifeboat as described in [4.5.2.5] and [4.5.2.8]. The wave-induced velocity $v_s$ of the launch skid or hook shall be added to the initial velocity for the free-fall phase through air.

Guidance note:
The wave-induced motion of the floater in a given sea-state can be calculated from the motion transfer functions $H_i(\omega)$ for six degrees of freedom $i = 1, \ldots, 6$ and a wave spectrum $S(\omega, \theta)$ characterizing the sea state. $\omega$ is the angular frequency and $\theta$ is the mean
propagation direction of the waves. Methods for calculating the motion transfer function and the resulting motion of a given location (i.e. the launch skid) on the floater are described in DNV-RP-C205.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

Figure 4-6 The wave surface elevation (solid line), horizontal water particle velocity (dash-dotted line), and vertical water particle velocity (dotted line) at the wave surface for a 5th order Stokes wave with $H = 17.2$ m, $T = 10.6$ s, $A_C = 9.92$ m, $A_T = 7.28$ m, $u_{\max} = 6.7$ m/s, $w_{\max} = 4.7$ m/s.

4.5.3 Trajectory through the water

4.5.3.1 The trajectory through the water for a given lifeboat geometry depends on the translational and rotational velocity at the start of water entry, the total mass and its mass distribution, and the local wave properties at the impact position. The wave properties include wave surface elevation and slope, as well as fluid particle kinematics (velocity and acceleration) beneath the wave surface. The mass distribution shall reflect how the occupants are distributed in the cabin. The presence of a strong current may influence the trajectory through the water. In such case, the effect of the current shall be included when the characteristic loads are calculated.

4.5.3.2 The trajectory through the water shall be predicted to form part of the basis for load calculations.

4.5.3.3 Depending on the initial conditions at the start of water entry, the following four motion patterns may occur for launches in calm water:

I) The lifeboat pitches significantly at maximum submergence and ascent so that it surfaces with a positive (forward) velocity.

II) The lifeboat pitches significantly at maximum submergence and ascent but the forward velocity is reduced to zero and it surfaces with a negative (backward) velocity.

III) After reaching the maximum depth in water, the lifeboat moves backwards, keeping almost the same angular position, then exits the water surface with a negative (backward) velocity and, after slamming onto the water surface, moves backwards with a low velocity.

IV) As a special case of III), the lifeboat exits the water surface at an almost vertical angle, vaulting into the air, and drops down onto the water surface with great impact and with a resulting motion in an arbitrary direction.

These motion patterns are depicted in Figure 4-7. Similar motion patterns will occur for launches in waves. Motion patterns III) and IV) are often referred to as log dive.

4.5.3.4 For a given lifeboat, launch skid arrangement and launch height, the motion pattern and possible log dive behaviour depend on the angle of attack, the hit point in the wave cycle and the water particle kinematics at the point of impact. The angle of attack at the point of impact may be strongly influenced by wind. Other parameters that may be important for log dive are the longitudinal position of the centre of gravity, the radius of gyration and the bow shape.
4.5.3.5 The lifeboat geometry, the lifeboat mass and its distribution, and the lifeboat launch system shall be designed so that motion pattern I) is achieved in all conditions. This motion pattern is desired since the lifeboat in still water will move away from the platform even if the lifeboat engine does not start. Motion pattern II) may occur during water entry in waves requiring the use of the lifeboat engine to move away from the platform. Motion patterns III) and IV), referred to as log dive, shall be avoided.

Guidance note:
Depending on the initial free-fall conditions, the wind speed and wind direction and the hit point in the wave cycle, log dive may occur. Log dive may lead to violent and unpredictable motions of the lifeboat after resurfacing and to a second water entry with random orientation. Another critical aspect of log dive is the increased submergence of the lifeboat, leading to unacceptable hydrostatic pressure loads. The most evident cause of log dive is a strong head wind or launch from a damaged host facility with a reduced skid angle and increased launch height. To identify a possible irregular motion after resurfacing during a numerical simulation of the trajectory, the following indicators can be used:

\[ \ddot{x} - u_w < 0 \]
\[ \ddot{x} < 0 \]

where \( \ddot{x} \) is the horizontal velocity of the lifeboat and \( u_w \) is the wave particle velocity at the point of resurfacing (when the centre of gravity of the lifeboat crosses the wave surface). This means that for launches in head wave condition, a negative horizontal motion...
at resurfacing (towards the host structure) may still imply an acceptable trajectory as long as it is less (in absolute value) than the wave particle velocity.

If the above criteria are not fulfilled, log dive can still occur if the maximum negative longitudinal velocity $v_x'$ of the lifeboat during its ascent to the surface satisfies the following criterion

$$v_x' < -\sqrt{2gV_{CG}}$$

where $V_{CG}$ is the vertical position of the centre of gravity (in the local lifeboat coordinate system). The longitudinal velocity is the lifeboat velocity in the stern-bow direction in the local coordinate system. See Figure 4-8.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

Figure 4-8  Velocity indicators for log dive

4.5.3.6 For numerical assessment of the effect of the wave surface and wave kinematics on the trajectory through the water when launching in a sea state $(H_s,T_p)$, a regular wave with wave height $H$ shall be defined as the expected value in the short term wave height distribution.

Guidance note:
The expected wave height $H$ in a sea state $(H_s,T_p)$ can be taken as $H = 0.59H_s$ from the Rayleigh distribution, with the spectral width parameter $\nu = 0.37$ as given in Subsection [3.3]. The corresponding wave period $T$ can be taken as the period of a regular Stokes $5^{th}$ order wave where $H/\lambda = 1/10$ and the wavelength $\lambda$ is related to $T$ by the dispersion relation

$$\lambda = \frac{gT^2}{2\pi}$$

valid for large water depths $d > \lambda/2$. The dispersion relation for moderate and shallow waters is given in [3.3].

A large wave is by nature asymmetric, with a higher crest height $A_C$ than trough depth $A_T$. The wave height is the sum $H = A_C + A_T$. The asymmetry increases with the steepness of the wave. For deep-water locations, the asymmetry factor $A_C/H$ can be approximated by the formula

$$A_C/H = 0.50 + \frac{7H}{gT^2}$$

For moderate water depths $d$, the asymmetry factor can be found from Stokes $5^{th}$ order wave theory for given parameters $H,T$ and $d$. The hydrodynamic forces on the lifeboat during water entry are a function of the relative velocity between the falling lifeboat and the water particle velocities in the wave. In high sea states where the wave kinematics will have an effect on the trajectory through the water, the wavelength can be assumed to be much longer than the characteristic dimension of the lifeboat, so that the wave kinematics can be taken as constant during this phase.

The maximum horizontal water particle velocity occurs at the top of the crest and can for an undisturbed wave be taken as

$$u_{\text{max}} = \frac{\pi H}{T} \exp \left( \frac{2\pi^2 H}{gT^2} \right)$$

when the effect of waves on the trajectory is to be assessed in a preliminary design phase.

The largest negative horizontal water particle velocity (in the opposite direction of the wave propagation velocity) occurs at the bottom of the trough and can be taken as

$$u_{\text{min}} = \frac{\pi H}{T}$$

The maximum vertical water particle velocity occurs close to the still water level crossing and can be taken as

$$w_{\text{max}} = \frac{\pi H}{T}$$

The variation of velocity with depth in deep water is given by the factor $f_w = \exp(kz)$ where $k$ is the local wave number given by

$$k = \frac{4\pi^3}{gT^2}$$
and where

\[ H = \text{wave height} \ [\text{m}] \]
\[ T = \text{wave period} \ [\text{s}] \]
\[ g = \text{acceleration of gravity} = 9.81 \ \text{m/s}^2. \]

Figure 4-6 shows the variation of horizontal and vertical water particle velocity at the surface of an extreme wave condition. The horizontal and vertical water particle velocity close to a large-volume host structure will be greater than in an undisturbed wave due to wave diffraction effects. Guidance regarding diffracted wave kinematics is given in DNV-RP-C205.

The short-term distribution of load in a given sea state can be estimated from a large number of launches at random points in time over a three-hour period and the maximum loads in each launch are found from a database of CFD simulations of trajectories and loads for various hit points and wave heights.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

Figure 4-9  Nonlinear regular wave

4.5.3.7 The wave diffraction effect caused by the submerged part of the host structure shall be taken into account. The wave surface elevation and wave kinematics at the position of lifeboat water entry shall be used to assess the lifeboat trajectory and loads.

Guidance note:
The wave diffraction effect depends on how transparent the submerged part of the host structure is. For a jacket structure where the substructure consists of slender tubular structures, the wave diffraction effect can be neglected. For large-volume host structures like semisubmersibles, TLPs, spars and FPSOs, a wave diffraction analysis should be carried out. Guidance on wave diffraction analysis is given in DNV-RP-C205.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

4.5.3.8 The trajectory through the water can be divided into four different phases:

— water entry phase
— ventilation phase
— maximum submersion phase
— ascent phase.

The four phases are further described in [4.5.3.9] through [4.5.3.12].

4.5.3.9 The water entry phase is characterized by large slamming forces. The start of this phase is defined as the instant of first contact between the lifeboat and water surface and continues until the aft end crosses the still water level. During this phase, the vertical and horizontal motions are retarded and the angular velocity of the lifeboat is reversed.

Guidance note:
The retardation of the lifeboat motion and change of angular velocity strongly affect the acceleration-induced loads on occupants and should therefore be minimized. For water entry on a wave surface, the slamming force is governed by the relative velocity between the lifeboat (including rotational motion) and the water particle at the point of entry. During the water entry phase, the water particle velocity in the wave can be considered constant in space and time.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

4.5.3.10 The ventilation phase is characterized by the generation of an air cavity behind and above the lifeboat. The size of the cavity depends on the lifeboat-stern geometry. During this phase, parts of the lifeboat are not in contact with water, leading to a buoyancy force that is not vertical. The direction of the total force on the lifeboat is opposed to the velocity of the lifeboat, leading to large retardation.
Guidance note:
Generation of an air cavity contributes to stronger retardation and should therefore be minimized. The cavity is eventually pinched off from the free surface. For a short duration, a closed air cavity (bubble) stays attached to the stern of the lifeboat and oscillates. At pinch-off, the air cavity splits in two - one part at the free surface which is open to the atmosphere and one closed part (bubble) which is attached to the stern/canopy of the lifeboat. Just after pinch-off, the pressure in the closed cavity oscillates leading to an oscillatory pressure on the lifeboat and resulting unsteady (oscillatory) retardation of the boat and pressure on the stern.

4.5.3.11 The maximum submersion phase is characterized by approximately constant forward velocity and a small vertical component of velocity of COG. The maximum submersion depth is defined as the depth of the position at which the vertical component of velocity of COG becomes zero. At maximum depth, the hydrostatic pressure takes on its maximum value.

Guidance note:
It is conceivable that the maximum depth of the bow could become the maximum depth of the COG plus up to about half the length of the lifeboat.

4.5.3.12 The ascent phase is characterized by an upwards vertical velocity of COG. This phase ends when the lifeboat exits the water and becomes free floating.

4.5.3.13 It is recommended to calculate a range of possible trajectories in order to reflect the variability in governing parameters as defined in [4.5.2.5] and [4.5.2.8].

Guidance note:
The trajectory shall usually be determined for a set of different situations, including launching from an intact structure and launching from a damaged structure. When the trajectory is to be determined for a lifeboat which is to be launched from a floating structure in a damaged condition, the launch height and launch angle may be different from the launch height and launch angle in the intact condition owing to the list and trim associated with the damaged condition.

4.5.3.14 Basically, the trajectory through the water can be predicted by three different methods:

— simplified numerical models for the different phases of the trajectory through the water
— CFD methods
— model tests.

4.5.3.15 A simplified numerical method for predicting the trajectory through the water is based on specifying the position-dependent and velocity-dependent forces and moments acting on the lifeboat and solving the equations of motion by time integration. For an arbitrary launch and wave propagation direction, a six degree of freedom model should be applied allowing for translational motion in three spatial directions and for rotation about three axes. Such a simplified numerical method shall be validated by CFD analysis or against model tests.

Guidance note:
During the partly submerged and fully submerged phases, the lifeboat is acted upon by hydrostatic and hydrodynamic forces. The hydrodynamic forces are functions of fluid pressure and velocities which depend on the motion of the lifeboat. Hence the hydrodynamic problem and the equations of motion of the lifeboat must be solved as a coupled problem at each time step.

4.5.3.16 CFD can be used to calculate the pressure distribution and the global force and moment on a lifeboat during its motion through air and water. The exact fluid dynamic equations are solved with respect to the pressure distribution, global force and moment, and motion of the lifeboat. The CFD method used should allow modelling of turbulence, two-phase flow with compressible air and the break-up of water particles. When applying CFD, convergence tests shall be carried out to ensure that the fluid cells and the temporal discretization are adequately representative of the physical spatial and temporal scales. The computational domain shall be large enough to avoid reflections from boundaries of the domain. Numerical results based on CFD should be validated against benchmark model test results.

Guidance note:
Numerical methods suitable for modelling the violent fluid flow during lifeboat impact are the Volume-of-Fluid (VOF) method and Smoothed Particle Hydrodynamics (SPH) method. The VOF method requires the generation of a volume mesh around the lifeboat. The SPH method only needs a surface description of the lifeboat.
4.5.3.17 A minimum clearance between the lowermost point of the lifeboat and the seafloor shall be demonstrated at any point in time during the lifeboat’s travel through the water in the launch operation. The minimum clearance shall be 10% of the water depth and not less than 5 m. This requirement shall be met in every conceivable condition for the lifeboat, cf. [4.2.2.3].

4.5.4 Sailing phase

4.5.4.1 In the sailing phase, the lifeboat is in a stable free-floating position responding to wave, wind and current forces. In the absence of any propulsive force, wave forces will cause an oscillatory motion of the lifeboat superimposed on a steady drift motion in the waves’ main propagation direction. Wind and current forces will act in the respective directions of wind and current. The forces and corresponding motion from waves, wind and current can be assumed to be independent and added.

4.5.4.2 The forward thrust force from the propulsion system shall be large enough to overcome wind, wave and current forces when these all act together in a direction towards the host facility, cf. Sec.7.

Guidance note:
The resistance forces against the forward motion of the lifeboat include the following components:
- wind force
- current force
- wave generating resistance
- added resistance due to waves
- frictional resistance.

4.5.4.3 In severe weather conditions, the hull and canopy of the lifeboat may exposed to large breaking-wave impact forces and resulting green water loads of similar magnitude to the impact forces experienced during the launch phase of partly submerged lifeboats. Guidance for calculating wave impact pressures is given in DNV-RP-C205.

4.5.5 Load cases for the ultimate limit state and accidental limit state

4.5.5.1 When investigating the lifeboat's behaviour and determining the loads on the lifeboat during the launch operation, the following four phases from water entry onwards shall be considered:

- water entry phase
- ventilation phase
- maximum submersion phase
- ascent phase.

During each phase, the stresses and deformations of relevance to all possible governing load cases shall be calculated for use in the design rules that shall be complied with during the design.

4.5.5.2 A set of five load cases to be considered for structural design and for assessing accelerations causing human loads is specified. The five load cases are to be considered as a minimum set of load cases to be investigated. Other load cases may exist which may govern the design. All relevant load cases shall be investigated. The minimum set of five load cases consists of:

- slamming pressure on the hull from water entry until maximum acceleration is reached
- inertia forces on the boat during maximum acceleration
- local effects during the ventilation phase
- pressures at maximum submersion
- suction on sides during the ascent, related to pressure distribution from the relative velocity squared.

The five load cases are further described in [4.5.5.3] through [4.5.5.7]. For each load case, pressures on particular points as well as differential pressures shall be considered, whichever is critical with respect to the structural design and human accelerations.
4.5.5.3 The slamming pressure on the hull from the time of water entry until maximum acceleration is reached shall be investigated.

Guidance note:
Loads on the hull at water entry and shortly afterwards will typically evolve from a very high local slamming pressure initially to a high dynamic pressure over a larger part of the hull in the ventilation phase. The upward force acting on the hull in this phase will be equal to the upward component of the pressures integrated over the wet hull area. The highest total upward force will coincide in time with the highest boat accelerations. The hull response from water entry until maximum acceleration is usually dynamic and can be determined by a dynamic analysis of the hull.

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4.5.5.4 The inertia forces on the boat during maximum acceleration shall be investigated.

Guidance note:
This load case takes place during the ventilation phase at the time of the maximum upward force. The load case is concerned with the inertia forces that act on the structure when the mass of its structural members are subjected to the maximum acceleration. This load case can be investigated as part of a dynamic analysis of the hull. It is expected to be more important for drop-launched boats than for skid-launched boats, since larger accelerations and smaller submersion are expected for drop-launched boats.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.5.5.5 During the typically turbulent downward motion phase after water entry, various local dynamic effects shall be investigated as relevant.

Guidance note:
On a skid-launched boat, the front of the wheelhouse will often be exposed to slamming. Depending on the shape of the stern of the lifeboat an air pocket may be created behind the boat when it enters the water and becomes submerged. When this air pocket subsequently implodes, dynamic water pressures will develop behind the boat and will – depending on the launching arrangement, the shape of the boat and the resulting boat trajectory – act on the aft wall, the wheelhouse or the roof. To capture the detailed fluid motion and resulting pressure loads in this phase using CFD, two-phase modelling with compressible air may be required. Model tests or full-scale tests can be used to determine which areas of the boat will be exposed to dynamic water pressures from imploding air pockets and load cases can be specified accordingly. It should be noted that scale effects may be important for the hydrodynamic pressure during the implosion of the air pocket.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.5.5.6 At the point of maximum submersion, the pressure field around the lifeboat due to hydrodynamic pressure at maximum acceleration governs the load on the hull and canopy. The load case resulting from this pressure distribution shall be investigated.

Guidance note:
At the point of maximum submersion, the vertical component of the acceleration will reach its maximum value. This will give a pressure distribution over the hull and canopy which can lead to large differential pressures. This pressure distribution can in a simplified analysis be represented by linear potential theory, which gives pressure terms equal to \( \rho \cdot \frac{\partial \phi}{\partial t} \), where \( \rho \) denotes the mass density of water, \( \phi \) denotes the velocity potential and \( t \) denotes time.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.5.5.7 After maximum submersion, the lifeboat will accelerate upwards until it reaches the surface. During this ascent, the pressure distribution over the lifeboat hull and canopy attributed to the effects of relative velocity squared governs the load on the hull and canopy. The load case resulting from this pressure distribution at the point of maximum upward speed shall be investigated.

Guidance note:
This load case can be investigated by applying the relevant hydrostatic pressure, corrected by a negative pressure on the sides of the boat and by an overpressure on the roof, caused by the upward speed.

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4.5.5.8 In assessing the loads on the lifeboat in the different phases during and after a launch, the effects of asymmetry should be considered, e.g. asymmetry due to waves propagating at an angle, an unsymmetrical load, skewed ascent and poor directional stability.

4.5.6 Slamming loads

4.5.6.1 A general description of slamming pressures and slamming loads can be found in DNV-RP-C205.
4.5.6.2 Determining the slamming loads on a lifeboat during impact is considered complex and difficult to describe using simple expressions. In particular, the complexity increases significantly when waves are included. General slamming simulation software or CFD codes can be used to analyse slamming. However, the design of the hull, canopy and wheelhouse will have to rely on model testing and/or full-scale testing to determine and calibrate slamming pressures and distributions.

4.5.6.3 Results from general slamming simulation software or CFD codes should be validated by model tests or full-scale tests.

Guidance note:
CFD is a suitable tool for determining the slamming pressures on a lifeboat. One standard numerical method is the Volume-of-Fluid (VoF) method which allows for the break-up of fluid particles and changed topology of the fluid domain. A fully nonlinear potential flow Boundary Element Method (BEM) may also be used with special boundary conditions at intersection points. 3D analysis is required and convergence tests must be performed to ensure that fluid cells are sufficiently small. Further, the computational domain should be large enough to avoid reflections from the boundaries. When applying CFD, convergence tests shall be carried out to ensure that the fluid cells and temporal discretization are adequate to represent the physical spatial and temporal scales.

4.5.6.4 The importance of carefully conducted model and full-scale testing when determining slamming pressures and distributions is emphasized. This implies that a sufficient number of pressure sensors are installed, enabling the subsequent use of data from these sensors in structural analyses of the hull, canopy and wheelhouse. See further details in Sec.9.

4.5.6.5 The parameters characterizing slamming on a rigid body with a small deadrise angle $\beta$ (see the definition in Figure 4-10) are the position and actual value of the maximum pressure, the time duration and the spatial extent of high-slamming pressures. Figure 4-10 presents a schematic view of the water entry of a two-dimensional body into a calm water surface. During impact, the free surface is deformed, resulting in spray and the formation of a jet.

![Figure 4-10 Schematic view of the water entry of a body into a calm free surface](image)

4.5.6.6 The complexity involved in determining slamming pressures increases significantly when taking into account waves from an arbitrary direction during a lifeboat launch. This implies that there will be an asymmetric (3D) distribution of pressures around the lifeboat and, for example, 2D-type simulations will fail to describe the actual pressure distribution adequately. A similar type of consideration applies when damage conditions (floater heel/trim) are to be simulated.

4.5.6.7 It is assumed that the deadrise angle, $\beta$, will be larger than 30° to 40° for free-fall lifeboats so that no spatial averaging of slamming pressures will be required. If, for some reason, the deadrise angle will be less than 30°, special considerations may have to be made.

4.5.6.8 Slamming loads will cause structural deformations of or vibrations in the lifeboat during impact. The hydrodynamic loading will hence be affected, since the slamming pressure is a function of the structural deformations. In general, it is considered conservative to neglect such hydroelastic effects.

4.5.7 Inertia loads

4.5.7.1 The lifeboat may be exposed to high accelerations during the launch. These accelerations can introduce high reaction loads on different parts of the lifeboat's external and internal structures. Acceleration levels shall be evaluated at different positions on the lifeboat wherever inertia loads due to local mass concentrations can occur.
4.5.8 Load distributions

4.5.8.1 The distribution of the hydrodynamic pressure loads over the wetted surface of the lifeboat causes structural deformation and is important for assessing the lifeboat’s structural integrity. When multiple choices of load distributions are relevant, the most conservative distribution shall be selected based on knowledge of the lifeboat hull structure.

4.5.8.2 The load distributions related to the different launch phases shall be specified. The distributions shall be specified related to both the cross sections (transverse frame related) and the longitudinal direction of the lifeboat (fore- and aft-related).

4.5.8.3 Different load distributions shall be given depending on the degree of submergence of the lifeboat during its motion through water, i.e. depending on whether it is partly submerged or fully submerged. The degree of submergence shall be defined based on conditions prevailing during the launch into calm water from the nominal launch height.

4.5.8.4 The lifeboat is referred to as fully submerged when the vertical distance $d_{\text{max}}$ from the still water level to the roof of the lifeboat at the time of maximum submergence is larger than $H_L/2$, where $H_L$ is the height of the lifeboat. The distances $d_{\text{max}}$ and $H_L$ shall be measured from the top of the roof at the longitudinal centre of the lifeboat. See Figure 4-11.

4.5.8.5 The lifeboat is referred to as partly submerged when the vertical distance $d_{\text{max}}$ from the still water level to the roof of the lifeboat at the time of maximum submergence is smaller than $H_L/2$, where $H_L$ is the height of the lifeboat. The distances $d_{\text{max}}$ and $H_L$ shall be measured from the top of the roof at the longitudinal centre of the lifeboat.

Figure 4-11 Definition of maximum submergence

4.5.8.6 The load distribution for a lifeboat which is fully submerged at maximum depth shall be specified for each of the following launch phases:

— the water entry phase
— the ventilation phase
— the maximum submergence phase
— the ascent phase
— the sailing phase.

Guidance note:
The ventilation phase is a transient phase which comes about when the lifeboat enters the water and creates an air pocket behind the stern. The ventilation phase is also known as the cavity transition phase.

Figure 4-12 Ventilation phase. Development of air pocket behind stern.
4.5.8.7 The load distribution for a lifeboat which is partly submerged at maximum depth is more complex and it is difficult to differentiate between well-defined phases. The following phases can, however, be used when load distributions are to be specified:

— the water entry phase
— the partly submerged horizontal acceleration phase
— the sailing phase.

4.5.8.8 CFD analysis can be used to establish hydrodynamic pressure load distributions over the wetted surface of the lifeboat.

4.5.9 Fatigue loads

4.5.9.1 For design against failure in the fatigue limit state, the expected load effect history of mean stress, stress range and number of stress cycles at each stress level shall be applied. This load effect history includes, but is not limited to, effects from one emergency launch of the lifeboat at an arbitrary point in time and effects from several operational test launches in calm water and water with relaxed wave conditions.

4.5.9.2 For requalification of a lifeboat, which has been used for one or more emergency launches in the past, sufficient safety against failure in the fatigue limit state shall be ensured, with due consideration paid to the load effect history created by the previous use of the lifeboat.

4.6 Accidental loads (A)

4.6.1 General

4.6.1.1 Accidental loads are loads related to abnormal operations or technical failure. Examples of accidental loads are loads caused by:

— impact from dropped objects
— impact when launched on objects
— collision impact (impact from ship collisions, or from collision with the host facility)
— explosions
— fire, including burning sea surface
— breaking waves in the sailing phase
— accidental impact from a vessel, helicopter or other object
— unintended change in ballast distribution
— unintended distribution of occupants, in particular asymmetrical distribution of occupants
— unintended loads from damaged skid and their possible unfavourable effects on the trajectory.

4.6.1.2 Sufficient robustness during stowage to resist minor impacts e.g. from dropped tools is normally ensured by the requirements for minimum scantlings given in Sec.6. Such impacts are considered part of normal use and are not considered accidents. Hence, there is no need to explicitly define accidental loads to represent such scenarios.

4.6.1.3 This standard is based on the assumption that the lifeboat station is protected from the hazard areas of the host facility to ensure that the lifeboat will not be exposed to severe blasts from explosions or high temperatures or heat fluxes from a fire. Hence blast and fire loads when the lifeboat is stowed need not be considered.

4.6.1.4 Sufficient robustness to resist the impact from striking minor floating objects in the impact-phase of a launch is normally ensured by the minimum scantling requirements stipulated in Sec.6. For free-fall lifeboats, it is not considered feasible to develop a hull structural design that protects the occupants from a collision with a major floating object, such as e.g. another lifeboat or a large piece of floating debris, in the impact phase of a launch.

4.6.1.5 Sufficient robustness to resist minor impacts that may occur during the use of the lifeboat, e.g.
from helicopter rescue operations, is normally ensured by the minimum scantling requirements stipulated in Sec.6. Such impacts are considered part of normal use and are not considered accidents. Hence, there is no need to explicitly define accidental loads to represent such scenarios.

4.6.1.6 Free-fall lifeboats are not normally designed to survive collisions with other ships or the host facility. The key design target is to avoid such collisions. However, the inherent robustness of structures designed in accordance with this code provides some collision survivability and the buoyancy requirements provide some survival capability if the hull is flooded due to a collision.

4.7 Deformation loads (D)

4.7.1 General

4.7.1.1 Deformation loads are loads caused by inflicted deformations such as:
— temperature loads
— built-in deformations.

4.7.2 Temperature loads

4.7.2.1 Structures shall be designed for the most extreme temperature differences they may be exposed to.

4.7.2.2 The ambient sea or air temperature shall be calculated as the extreme value whose return period is 100 years.

4.7.2.3 Structures shall be designed for a solar radiation intensity of 1000 W/m².

4.8 Load effect analysis

4.8.1 General

4.8.1.1 Load effects, in terms of motions, displacements and internal forces and stresses in the structure, shall be determined with due consideration of:
— their spatial and temporal nature including:
   — possible nonlinearities of the load
   — the dynamic character of the response
— the relevant limit states for design checks
— the desired accuracy in the relevant design phase.

4.8.1.2 Permanent loads, functional loads, deformation loads and fire loads can generally be treated using static analysis methods. Environmental loads (caused by wind, waves, current, ice, water level and earthquake) and certain accidental loads (caused by impacts and explosions) may require dynamic analysis. Inertia and damping forces are important when the periods of steady-state loads are close to natural periods or when transient loads occur.

4.8.1.3 Uncertainties in the analysis model are expected to be taken care of by the load and resistance factors. For acceleration loads in the human body, for which load and resistance factors are not used, such model uncertainties are expected to be taken care of by the requirements set for the acceptable threshold values. If uncertainties are particularly high, conservative assumptions shall be made.

4.8.1.4 If analytical models are particularly uncertain, the sensitivity of the models and the parameters utilized in the models shall be examined. If geometric deviations or imperfections have a significant effect on load effects, conservative geometric parameters shall be used in the calculation.

4.8.1.5 In the final design stage, theoretical methods for predicting important responses of any novel system should be verified by appropriate model tests. Full-scale tests may also be appropriate.
4.8.2 Global motion analysis

4.8.2.1 A global motion analysis is an analysis of the rigid body motion of the lifeboat in all phases during and after launch. The purpose of such a motion analysis is to determine displacements, accelerations, velocities and hydrodynamic pressures relevant for the loading on the lifeboat structure. Excitation by waves, current and wind should be considered.

4.8.3 Load effects in structures

4.8.3.1 Displacements, forces and stresses in the structure shall be determined for relevant combinations of loads by means of recognized methods which take adequate account of the variation of loads in time and space, the motions of the structure and the limit state which shall be verified. Characteristic values of the load effects shall be determined.

4.8.3.2 Nonlinear and dynamic effects associated with loads and structural response shall be accounted for whenever relevant.

4.8.3.3 The stochastic nature of environmental loads shall be adequately accounted for.

4.9 Stowage loads

4.9.1 General

4.9.1.1 During stowage in the lifeboat station, the lifeboat will be subject to loads from the davit arrangement, the hook system and the skid system as well as loads associated with the self-weight of the lifeboat. The lifeboat shall be designed against these loads.

4.9.1.2 Wind loads may act on the lifeboat during its stowage in the lifeboat station and shall be accounted for in the design.

4.9.1.3 The performance of a lifeboat in a given emergency situation may depend on accumulated loads during stowage and on accidental loads from the launch system. Such loads shall be identified and analysed.

4.9.1.4 If waves are allowed to act on the stowage position or there is a potential for run-up in the stowage position, which is not usually acceptable, relevant slamming loads from waves on the lifeboat shall be investigated.

4.9.2 Snow and ice loads

4.9.2.1 Loads from snow and ice shall be considered.

4.9.2.2 Snow and ice loads due to snow and ice accumulation may be reduced or disregarded if a snow and ice removal procedure is established.

4.9.2.3 Possible increases in cross-sectional areas and changes in surface roughness caused by icing shall be considered wherever relevant. This is particularly important whenever wind loads and hydrodynamic loads are to be determined and also when the friction between the lifeboat and skid is to be assessed for skid-launched lifeboats.

4.10 Load factors for design

4.10.1 Load factors for the ultimate limit state - launching

4.10.1.1 For design against failure in the ULS during launching, one set of load combinations shall be considered, as specified in Table 4-4, which also specifies the load factor requirements.

Table 4-4 Load factors $\gamma$ for the ULS - launching

<table>
<thead>
<tr>
<th>Load factors</th>
<th>Load categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>1.0</td>
</tr>
</tbody>
</table>
4.10.2 Load factors for the ultimate limit state - stowage

4.10.2.1 For design against failure in the ULS during stowage, two sets of load combinations shall be considered, as specified in Table 4-5, which also specifies the load factor requirements. The load factor for an environmental load shall be used in ULS analyses for design as a factor on the characteristic environmental load or load effect, defined as the 99% quantile in the distribution of the annual maximum load or load effect, whichever is applicable.

Guidance note:
Contrary to environmental loads during launching, which arise from brief exposure to the environment at an arbitrary point in time, environmental loads during stowage arise from continuous exposure to the environment over a longer period of time. This is reflected in different definitions of the characteristic environmental load and in different load factor requirements, cf. the difference between Table 4-4 and Table 4-5. During stowage in the lifeboat station, environmental loads are expected to arise mainly from wind and maybe from snow and ice, but not from waves, since the lifeboat station is presumed to be located at a level with a sufficient air gap to prevent any waves from reaching the lifeboat.

The three-second gust with a 100-year return period can be used as a basis for calculating the 99% quantile in the distribution of the annual maximum wind load or wind load effect.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.10.3 Load factor for the accidental limit state

4.10.3.1 The load factor $\gamma_f$ in the ALS is 1.0.

4.10.4 Load factors for design of hooks and attachments

4.10.4.1 For design of hooks and attachments for the launching system, two load combinations shall be considered as specified in Table 4-6, which also specifies the load factor requirements for each combination. The load factor requirements apply to design during stowage as well as to the design during launching prior to the release of the lifeboat.

Table 4-5 Load factors $\gamma_f$ for the ULS - stowage

<table>
<thead>
<tr>
<th>Load combination</th>
<th>Load categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G</td>
</tr>
<tr>
<td>(a)</td>
<td>1.3</td>
</tr>
<tr>
<td>(b)</td>
<td>1.0</td>
</tr>
</tbody>
</table>

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Table 4-6 Load factors $\gamma_f$ for design of hooks and attachments

<table>
<thead>
<tr>
<th>Load combination</th>
<th>Load categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G</td>
</tr>
<tr>
<td>(a)</td>
<td>1.3</td>
</tr>
<tr>
<td>(b)</td>
<td>1.0</td>
</tr>
</tbody>
</table>
SECTION 5 MATERIAL SELECTION AND MANUFACTURING

5.1 Introduction

5.1.1 Scope

5.1.1.1 The strength and deformation properties of materials shall be documented. This section provides criteria for structural categorization and corresponding selection of materials for lifeboat structures. Requirements for the strength and deformation properties of materials are given depending on the material type and category. Manufacturing requirements are given to the extent necessary to ensure that the strength and deformation properties assumed in design are achieved in construction. Inspection principles to be applied in design and construction of lifeboat structures are also given. The following materials are covered:

— steel
— aluminium
— raw materials for FRP composite structures, including fibre reinforcement, resin, gelcoat and topcoat, sandwich core material, sandwich adhesive and general adhesive for joints.

5.1.2 Temperatures for the selection of material

5.1.2.1 The design temperature for a structural component is the reference temperature used as a criterion for the selection of material quality. For structural components constructed from steel or aluminium, the design temperature shall be equal to or lower than the lowest daily mean temperature in the air in the areas where the lifeboat is to be transported, installed, stored and operated. For structural components constructed from composite or sandwich materials, two design temperatures shall apply. The design minimum temperature shall be equal to the design temperature defined for steel and aluminium. The design maximum temperature shall be equal to 80°C in areas exposed to direct sunlight. Otherwise, the maximum daily temperature can be used. Materials in the neighbourhood of machinery parts, etc., shall be able to withstand the local temperatures.

Guidance note:
For steel and aluminium, a low temperature is critical for the design, since a too low temperature may lead to brittle material behaviour. For composites, a high temperature is critical for the design, since a too high temperature will lead to soft material behaviour. However, for composites a low temperature can also be critical in some cases.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

5.1.2.2 The service temperatures for different components of the lifeboat structure apply as a basis for the selection of material quality.

5.1.2.3 Steel and aluminium components shall be designed for a service temperature not higher than the design temperature for the areas where the lifeboat is to be transported, installed, stored and operated. If two or more service temperatures apply to such a structural component, the lower specified value shall be applied in design.

5.1.2.4 Composite components shall be designed for both a minimum service temperature and a maximum service temperature. The minimum service temperature shall not be higher than the design minimum temperature. The maximum service temperature shall not be lower than the design maximum temperature.

5.1.2.5 Internal structures in permanently heated rooms need not be designed for service temperatures lower than 0°C.

5.1.3 Fire

5.1.3.1 The fire resistance of the selected materials shall be sufficient to meet the requirement given in [8.4.1.1]. Fulfilment of this requirement shall be documented by testing in accordance with specifications given in [9.3.6.1].
5.1.4 Inspections

5.1.4.1 Regardless of material type, inspections by means of nondestructive testing (NDT) can be used to monitor materials and document that their properties meet the requirements. Nondestructive testing can be used for inspections of materials during manufacturing as well as for periodic inspections during the lifeboat's service life.

5.2 Structural categorization

5.2.1 Structural categories

5.2.1.1 Structural categories are assigned to both metallic materials and composite components. The category shall be selected based on the criticality of the component. The requirements for the characterization and quality assurance of a material will depend on the structural category of the component in which the material is used.

5.2.1.2 Components are classified into structural categories according to the following criteria:

- significance of the component in terms of the consequence of failure
- stress condition at the considered detail that, together with possible weld defects or fatigue cracks, may provoke brittle fracture.

Guidance note:
The consequence of failure may be quantified in terms of the residual strength of the structure if a failure of the relevant component is taken into consideration.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.2.1.3 The structural category for the selection of materials shall be determined according to principles given in Table 5-1.

**Table 5-1 Structural categories for the selection of materials**

<table>
<thead>
<tr>
<th>Structural category</th>
<th>Principles for determining the structural category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Special</td>
<td>Structural parts where failure will have substantial consequences for the lifeboat and its passengers and which are subject to a stress condition that may increase the probability of a brittle fracture in the lifeboat and/or are constructed such that brittle failure is the dominant failure mode.(^1)</td>
</tr>
<tr>
<td>Primary</td>
<td>Structural parts where failure will have substantial consequences for the lifeboat and its passengers.</td>
</tr>
<tr>
<td>Secondary</td>
<td>Structural parts where failure will be without significant consequence for the lifeboat and its passengers.</td>
</tr>
</tbody>
</table>

\(^1\) In complex joints, a triaxial or biaxial stress pattern will be present. This may give conditions for brittle fracture when tensile stresses are present in addition to the presence of defects and material with low fracture toughness. Particular laminate lay-ups in FRP components combined with certain stress conditions, e.g. through thickness, may exhibit a brittle failure mode.

Guidance note:
According to the definition of structural categories in Table 5-1, structural components may exist that qualify both as primary structures and secondary structures. A stiffener, for example, will be “secondary” with respect to overloading from fluid pressures whereas it will be “primary” with respect to overloading from the global bending of the hull beam. Structural components that qualify for more than one structural category according to Table 5-1 shall always be considered according to the stricter category.

The term “secondary structures” is often used to mean entire objects like railings, masts and even small deckhouses that do not form part of the lifeboat's main hull structure and canopy.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.2.1.4 Requirements and guidance for the manufacturing of steel and aluminium materials are given in DNVGL-OS-B101. Supplementary guidance for the manufacturing of steel materials can be found in ENV 1090-1 and ENV 1090-5. Steel and aluminium products shall be delivered with the inspection documents defined in EN 10204 or an equivalent standard. Unless otherwise specified, material certificates according to Table 5-2 shall be presented for metallic materials.
5.2.1.5 Requirements and guidance for ensuring the quality of FRP composite materials are given in DNV-OS-C501 Sec.4 and Sec.5. Compliance with the requirements shall be documented according to Table 5-3.

Table 5-3 Material certificates for composite materials and sandwich materials

<table>
<thead>
<tr>
<th>Certification process</th>
<th>Structural category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test certificate</td>
<td>Special</td>
</tr>
<tr>
<td>Evaluation and inspection of the production process. Inspection and tests witnessed and signed by an independent third party body</td>
<td>Special</td>
</tr>
<tr>
<td>Work certificate</td>
<td>Primary</td>
</tr>
<tr>
<td>Evaluation of the production process. Inspection and tests results signed by QA department.</td>
<td>Primary</td>
</tr>
<tr>
<td>Test report</td>
<td>Secondary</td>
</tr>
<tr>
<td>Confirmation by the manufacturer that the supplied products fulfil the purchase specification, and test data from regular production, not necessarily from the products supplied</td>
<td>Secondary</td>
</tr>
</tbody>
</table>

5.2.2 Inspection categories for welds

5.2.2.1 NDT requirements for the type and extent of weld inspections are given in DNVGL-OS-C401 and depend on the inspection category assigned to the welds. The requirements are based on the consideration of fatigue damage and assessment of general fabrication quality.

5.2.2.2 The inspection category is by default related to the structural category according to Table 5-4.

Table 5-4 Inspection categories

<table>
<thead>
<tr>
<th>Inspection category</th>
<th>Structural category</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Special</td>
</tr>
<tr>
<td>II</td>
<td>Primary</td>
</tr>
<tr>
<td>III</td>
<td>Secondary</td>
</tr>
</tbody>
</table>

5.2.2.3 The weld connection between two components shall be assigned an inspection category according to the highest category of the joined components. For stiffened plates, the weld connecting the stiffener, stringer and girder web to the plate may be inspected according to inspection Category III.

5.2.2.4 If the fabrication quality is assessed by testing, or if its quality is well-known based on previous experience, the extent of the inspection required for elements within the structural category primary may be reduced, but the extent must not be less than that for inspection Category III.

5.2.2.5 Fatigue-critical details within the structural categories primary and secondary shall be inspected according to the requirements given for Category I.

5.2.2.6 Welds in fatigue-critical areas that are not accessible for inspection and repair during operation shall be inspected according to the requirements for Category I during construction.
5.3 Steel

5.3.1 General

5.3.1.1 For steel materials, the assignment of a structural category serves the purpose of assuring an adequate level of inspection and an adequate material quality. Conditions that may result in brittle fracture shall be avoided.

Guidance note:
Brittle fracture may occur due to the combination of:
- the presence of sharp defects such as cracks
- high tensile stress in the direction normal to planar defect(s)
- material with low fracture toughness.

Sharp cracks resulting from fabrication may be detected by inspection and can subsequently be repaired. Fatigue cracks may also be discovered during service life by inspection.

High stresses in a component may occur due to welding. A complex connection is likely to provide more restraint and larger residual stress than a simple one. This residual stress may be partly removed by post-weld heat treatment if necessary. In addition, a complex connection exhibits a more three-dimensional stress state due to external loading than a simple connection. This stress state may provide a basis for a cleavage fracture.

The fracture toughness depends on the temperature and material thickness. These parameters are accounted for separately in the selection of material. The resulting fracture toughness in the weld and heat-affected zone also depends on the fabrication method.

Thus, to avoid brittle fracture, firstly a material with a suitable fracture toughness for the actual design temperature and thickness is selected. Then a proper fabrication method is used. In special cases, post-weld heat treatment may be performed to reduce crack-driving stresses, see DNVGL-OS-C401. A suitable inspection programme is applied to detect defects and allow for the removal of planar defects larger than those considered acceptable. Steel qualities with an appropriate fracture toughness and inspection programmes to avoid unacceptable defects are achieved by assigning different structural categories and different inspection categories to different types of structural connections, see Table 5-1 and Table 5-4.

5.3.2 Structural steel designations

5.3.2.1 Wherever the subsequent requirements for steel grades depend on plate thickness, these requirements are based on the nominal thickness as built.

5.3.2.2 The requirements in this subsection deal with the selection of various structural steel grades in compliance with the requirements given in DNVGL-OS-B101. Where other codes or standards have been agreed on and utilized in the specification of steels, the application of such steel grades within the structure shall be specially considered.

5.3.2.3 The steel grades selected for structural components shall be related to calculated stresses and requirements for toughness properties. Requirements for toughness properties are in general based on the Charpy V-notch test and depend on the design temperature, structural category and thickness of the component in question.

5.3.2.4 The material toughness may also be evaluated by fracture mechanics testing in special cases.

5.3.2.5 In structural cross-joints where high tensile stresses are acting perpendicular to the plane of the plate, the plate material shall be tested to prove its ability to resist lamellar tearing, Z-quality, see [5.3.2.11].

5.3.2.6 Requirements for forgings and castings are given in DNVGL-OS-B101.

5.3.2.7 Material designations for steel are given in terms of a strength group and a specified minimum yield stress according to steel grade definitions given in DNVGL-OS-B101 Ch.2 Sec.1. The steel grades are referred to as VL grades. Structural steel designations for various strength groups are referred to as given in Table 5-5.
5.3.2.8 Each strength group consists of two parallel series of steel grades:

— steels with normal weldability
— steels with improved weldability.

The two series are intended for the same applications. However, the improved weldability grades have, in addition to leaner chemistry and better weldability, extra margins to account for reduced toughness after welding. These grades are also limited to a specified minimum yield stress of 500 N/mm².

5.3.2.9 Regardless of the strength group, the modulus of elasticity for structural steel shall be taken as $E_S = 2.1 \times 10^5$ N/mm².

5.3.2.10 Conversions between the VL grades used in Table 5-5 and steel grades used in the EN10025-2, -3, -4 and -6 standards are used for the sole purpose of determining plate thicknesses and are given in Table 5-6.

### Table 5-5 Material designations

<table>
<thead>
<tr>
<th>Designation</th>
<th>Strength group</th>
<th>Specified minimum yield stress $f_y$ (N/mm²)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>VL</td>
<td>Normal-strength steel (NS)</td>
<td>235</td>
</tr>
<tr>
<td>VL-27</td>
<td>High-strength steel (HS)</td>
<td>265</td>
</tr>
<tr>
<td>VL-32</td>
<td></td>
<td>315</td>
</tr>
<tr>
<td>VL-36</td>
<td></td>
<td>355</td>
</tr>
<tr>
<td>VL-40</td>
<td></td>
<td>390</td>
</tr>
<tr>
<td>VL-420</td>
<td>Extra-high-strength steel (EHS)</td>
<td></td>
</tr>
<tr>
<td>VL-460</td>
<td></td>
<td>460</td>
</tr>
<tr>
<td>VL-500</td>
<td></td>
<td>500</td>
</tr>
<tr>
<td>VL-550</td>
<td></td>
<td>550</td>
</tr>
<tr>
<td>VL-620</td>
<td></td>
<td>620</td>
</tr>
<tr>
<td>VL-690</td>
<td></td>
<td>690</td>
</tr>
</tbody>
</table>

¹) For steels with improved weldability the required specified minimum yield stress is reduced as the material thickness increases, see DNVGL-OS-B101.

### Table 5-6 Steel grade conversions ¹)

<table>
<thead>
<tr>
<th>VL grade</th>
<th>EN 10025-2</th>
<th>EN 10025-3</th>
<th>EN 10025-4</th>
<th>EN 10025-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>VL A</td>
<td>S235JR</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VL B</td>
<td>S235J0</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VL D</td>
<td>S235J2</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VL E</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VL A27S</td>
<td>S275J0</td>
<td>S275N</td>
<td>S275M</td>
<td>–</td>
</tr>
<tr>
<td>VL D27S</td>
<td>S275J2</td>
<td>S275N</td>
<td>S275M</td>
<td>–</td>
</tr>
<tr>
<td>VL E27S</td>
<td>–</td>
<td>S275NL</td>
<td>S275ML</td>
<td>–</td>
</tr>
<tr>
<td>VL F27S</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VL A32</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VL D32</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VL E32</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VL F32</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VL A36</td>
<td>(S355J0)</td>
<td>S355N</td>
<td>S355M</td>
<td>–</td>
</tr>
<tr>
<td>VL D36</td>
<td>S355K2, (S355J2)</td>
<td>S355N</td>
<td>S355M</td>
<td>–</td>
</tr>
<tr>
<td>VL E36</td>
<td>–</td>
<td>(S355NL)</td>
<td>S355ML</td>
<td>–</td>
</tr>
<tr>
<td>VL F36</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VL A40</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VL D40</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VL E40</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VL F40</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>
Guidance note:
Important notes to the conversions between VL grades and EN10025-2 grades in Table 5-6:

The conversions are based on comparable requirements for strength and toughness. VL grades are, in general, better steel qualities than comparable EN10025-2 grades. For example, all VL grades except VL A and VL B are fully killed and fine grain treated. This is only the case for the J2G3 and K2G3 grades in EN10025-2.

The delivery condition is specified as a function of thickness for all VL grades, while this is either optional or at the manufacturer’s discretion in EN10025-2.

The steel manufacturing process is also at the manufacturer’s discretion in EN10025-2, while only the electric process or one of the basic oxygen processes is generally allowed according to the DNV GL (VL) standard.

In EN10025-2, the minimum specified mechanical properties (yield stress, tensile strength range and elongation) are thickness dependent. The corresponding properties for VL grades are specified independently of thickness.

Because EN10025-3 specifies requirements for fine grain treatment, the EN10025-3 grades are in general better grades than corresponding grades listed in EN10025-2 and can be considered equivalent to the corresponding VL grades.

5.3.2.11 Within each defined strength group, different steel grades are given, depending on the required impact toughness properties. The grades are referred to as A, B, D, E, and F for normal weldability grades and AW, BW, DW, and EW for improved weldability grades as defined in DNVGL-OS-B101 Ch.2 Sec.1.

Additional symbol:

Z = steel grade with proven through-thickness properties. This symbol is omitted for steels with improved weldability although improved through-thickness properties are required.

5.3.2.12 The grade of steel to be used shall in general be selected according to the design temperature and the thickness for the applicable structural category as specified in DNVGL-OS-C101 Ch.2, Sec.3, Item 4.3, Table 5. The steel grades in DNVGL-OS-C101, Ch.2, Sec.3, Item 4.3, Table 5 are VL grade designations. National regulations may provide additional criteria for selecting the steel grade.
5.3.2.13 The selection of a better steel grade than the minimum required in design shall not lead to more stringent fabrication requirements.

5.3.2.14 The grade of steel to be used for a thickness less than 10 mm or design temperature above 0°C or both may be specially considered in each case.

5.3.2.15 Welded steel plates and sections with a thickness that exceeds the upper limits for the actual steel grade as given in DNVGL-OS-C101 Ch.2 Sec.3 Table 5 shall be evaluated in each individual case with respect to the fitness for purpose of the weldments. The evaluation should be based on fracture mechanics testing and analysis, e.g. in accordance with BS 7910.

5.3.2.16 For regions subjected to only compressive or only low tensile stresses or both, consideration may be given to the use of lower steel grades than those stated in DNVGL-OS-C101 Ch.2 Sec.3 Table 5.

5.3.3 Bolting materials

5.3.3.1 Bolt assemblies, which are considered essential for structural and operational safety, shall in general conform to the requirements given in a recognized standard such as ISO 898-1.

5.3.3.2 Bolting materials used in structural and mechanical bolted connections shall be consistent with the systems in which the connections are applied. Consideration shall be given to:

— the nature of the external loading
— the design and capacity of the bolted connection
— the load going through each bolt
— the consequence(s) of failure.

5.3.3.3 Bolts are categorized into Categories A and B according to Table 5-7. Bolting materials shall have material certificates according to EN 10204:2004 as specified in Table 5-7.

<table>
<thead>
<tr>
<th>Bolt category</th>
<th>Load condition 1)</th>
<th>Material certificate (EN 10204)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>No tension from external load; connection relying on friction.</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The tension from external loads is considered secondary and small compared to the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>bolt capacity. Some redundancy is required, for example no single point of failure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>of the bolt shall cause a risk of a failure of the structure.</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Nonredundant application</td>
<td>3.1 or 3.2</td>
</tr>
</tbody>
</table>

1) Bolts intended for use below −20°C are to be subject to special consideration. In general, bolts intended for temperatures below −20°C should be of austenitic stainless steel or the equivalent. Impact tests of bolts with austenitic stainless steel are not normally required.

5.3.3.4 Bolts with a diameter less than 16 mm shall not be used for load-bearing purposes in structures categorized as special or primary. Corresponding nuts shall be in accordance with a recognized standard. No impact testing is required for nuts and washers or other bolting elements mainly exposed to compressive loads.

5.3.3.5 Fasteners, i.e. bolts, nuts and washers, for use in marine environments shall normally be hot-dipped galvanized or sherardized with a minimum coating thickness of 50 micrometres. If special thread profiles or narrow tolerances prohibit such coating thickness, bolts and nuts can be supplied electroplated or black provided they are properly coated or painted after installation. Pickling and electroplating operations shall be followed by immediate hydrogen relief (degassing) treatment to eliminate embrittling effects. For ISO 898-1 Class 8.8 and 10.9 bolts and nuts, corrosion protection by galvanizing is an acceptable approach provided the galvanizing is removed from the contact surfaces prior to assembling.
Guidance note:
Zinc on the contact surfaces resulting from the galvanization will reduce the local compression strength of the surfaces and increase the fatigue loading on the bolts.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

5.3.3.6 Major structural or pressure-retaining bolts and nuts with a minimum yield strength above 490 N/mm² shall be manufactured from low alloy or alloyed steel and supplied in a quenched and tempered condition.

Guidance note:
Low alloy or alloy steels are considered to be those steels where one or more of the elements Cr, Mo and Ni comply with a specified minimum content of 0.40% (Cr), 0.15% (Mo) and 0.40% (Ni), respectively.

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5.3.3.7 For general service, when the application is in an atmospheric environment, the specified tensile properties shall not exceed those stipulated in ISO 898-1 Class 10.9. ISO 898-1 Class 12.9 may only be applied if the requirements as to the flatness of surfaces and for pretension according to recognized principles are fulfilled.

5.4 Aluminium

5.4.1 Material designations

5.4.1.1 Wherever the subsequent requirements for aluminium grades are dependent on plate thickness, these requirements are based on the nominal thickness as built.

5.4.1.2 The requirements in this subsection deal with the selection of various structural aluminium grades in compliance with the requirements given in DNVGL-OS-B101 Ch.2 Sec.5. Where other codes or standards have been agreed on and utilized in the specification of aluminium, the application of such aluminium grades within the structure shall be specially considered.

5.4.1.3 Forgings and castings shall conform to a recognized standard. Requirements can be found in ISO 3522 and EN 586.

5.4.1.4 Aluminium alloys are classified into grades according to chemical composition and into temper according to hardening method. The alloy grades are listed in DNVGL-OS-B101 Ch.2 Sec.5. Temper designations are also given in DNVGL-OS-B101 Ch.2 Sec.5. The numerical designations (grades) of aluminium alloys are based on those of the Aluminium Association. The designations are applicable to wrought aluminium products within the thickness range of 3 mm to 50 mm.

5.4.1.5 In this standard, a distinction is made between alloys which are capable of being strain hardened and alloys which are capable of being age hardened. 5000 series alloys are alloys capable of being strain hardened and are listed in DNVGL-OS-B101 Ch.2 Sec.5. 6000 series alloys are alloys capable of being age hardened and are also listed in DNVGL-OS-B101 Ch.2 Sec.5.

5.4.1.6 The prime alloy selection for main structural components should be alloy 5083 for plates and alloy 6005 or 6082 for profiles. The other alloys listed should be used for secondary applications. For weld filler material, alloy 5183 should be the prime selection. The use of 6000 series aluminium alloys in direct contact with seawater may be restricted depending on the application and corrosion protection system.

5.4.1.7 Mechanical properties in terms of yield strength and tensile strength are given in DNVGL-OS-B101 Ch.2 Sec.5 as functions of grade and temper.

5.4.1.8 Regardless of the grade and temper designation, the modulus of elasticity for structural aluminium shall be taken as $E_A = 6.9 \cdot 10^5$ N/mm².

5.4.1.9 Requirements and guidance for manufacturing aluminium materials are given in DNVGL-OS-C401. Aluminium materials and products shall be delivered with inspection documents as defined in EN 10204 or in an equivalent standard. Unless otherwise specified, material certificates according to Table 5-2 shall be presented.
5.5 Fabrication of metallic structures

5.5.1 Welding

5.5.1.1 Materials to be welded shall have good weldability properties. The requirement given in [5.5.1.2] applies.

5.5.1.2 When the relevant elements in the chemical composition of the structural steel are known, the following limitation on the carbon equivalent (CE) value shall be met:

\[ CE_{(0)} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15} \leq 0.45 \]

Materials not meeting this limitation may be used provided suitable welding procedures are applied.

**Guidance note:**
The welding of materials that do not meet the limitation on the chemical composition normally requires more stringent fabrication procedures regarding the selection of consumables, preheating, post weld heat treatment and NDT.

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5.5.2 Weld procedure qualification

5.5.2.1 Weld procedure requirements and welding requirements are given in DNVGL-OS-C401. These requirements shall be complied with. Requirements for welded connections are given in this standard, see [6.2.8].

5.5.3 Fabrication records

5.5.3.1 Fabrication records shall be maintained by the manufacturer in a traceable manner and shall contain relevant information regarding design specifications, materials, fabrication processes, inspection, heat treatment and testing.

5.5.3.2 Fabrication records for Category I and II equipment shall include the following particulars as applicable:

- nature of external loading
- manufacturer’s statement of compliance
- reference to design specifications and drawings
- location of materials and indication of respective material certificates
- welding procedure specifications and qualification test records
- location of weldings indicating where the particular welding procedures have been used
- heat treatment records
- location of nondestructive testing (NDT) indicating where the particular NDT method has been used and its record
- load, pressure and functional test reports
- as-built part numbers and revisions.

Equipment categorization is given in DNVGL-OS-D101 Ch.3 Sec.1 [2.3].

5.6 Laminates

5.6.1 Introduction

5.6.1.1 Laminates are produced in specific ways by combining fibres and resin to form a laminate. The laminates used in a lifeboat shall be clearly specified and all materials shall be traceable.

5.6.1.2 The methods described in DNV-OS-C501 may be used to calculate and document laminate properties.
5.6.2 Laminate specification

5.6.2.1 A minimum set of process parameters and constituent material characterizations is given in Table 5-8. All these items shall be specified.

Table 5-8 Basic information to identify a laminate

<table>
<thead>
<tr>
<th>Constituent materials:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic fibre type</td>
</tr>
<tr>
<td>Type of weave</td>
</tr>
<tr>
<td>Generic resin type (e.g. epoxy, polyester)</td>
</tr>
<tr>
<td>Specific resin type (trade name)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process parameters:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing method</td>
</tr>
<tr>
<td>Processing temperature</td>
</tr>
<tr>
<td>Processing pressure</td>
</tr>
<tr>
<td>Process atmosphere (e.g. vacuum)</td>
</tr>
<tr>
<td>Post curing (temperature and time)</td>
</tr>
<tr>
<td>Control of fibre orientation</td>
</tr>
<tr>
<td>Fibre volume fraction</td>
</tr>
<tr>
<td>Void content</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conditioning parameters:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
</tr>
<tr>
<td>Water content of the laminate (wet, dry)</td>
</tr>
<tr>
<td>Chemical environment</td>
</tr>
<tr>
<td>Loading rate</td>
</tr>
</tbody>
</table>

For each parameter:

<table>
<thead>
<tr>
<th>Measured values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guaranteed minimum values</td>
</tr>
<tr>
<td>Estimated standard deviation, based on tests</td>
</tr>
<tr>
<td>Number of specimens tested</td>
</tr>
</tbody>
</table>

5.6.2.2 A laminate is made up of a sequence of plies. All materials and the stacking sequence of the plies shall be clearly identified. The orientation of nonhomogeneous or anisotropic materials shall be clearly specified on the materials level and on the structural level.

5.6.2.3 The type of fabric shall be clearly specified for each ply, i.e. a specification of the fibre and weight of reinforcement per unit area. In addition, the fabrication method shall be specified, for example manual lamination and vacuum-assisted resin transfer moulding.

5.6.3 Laminate strength and stiffness

5.6.3.1 Strength and stiffness shall be represented in terms of characteristic values.

5.6.3.2 For laminates, characteristic values usually have to be established based on measurements of test specimens. The following statistical properties are needed to estimate the characteristic values from test data:

- Sample mean: \( \bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \)

- Sample standard deviation: \( s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2} \)

- Sample coefficient of variation: \( \text{COV} = \frac{s}{\bar{x}} \)

Here, \( x_i, i = 1, \ldots, n \) are the \( n \) observations of the material property to be estimated, obtained from tests.

5.6.3.3 The characteristic value of strength is defined as a low 2.5% quantile in the distribution of the arbitrary strength. When characteristic values of strength are estimated from data, the estimate shall be given with confidence. Characteristic values of strength for use in design shall be estimated with 95% confidence. Characteristic values can be estimated with confidence in accordance with Table 5-9.
5.6.3.4 The characteristic value of material stiffness used for strength calculations is defined as the mean value. The characteristic value of material stiffness used for deflection calculations is also defined as the mean value. The characteristic value of material stiffness can be estimated by the sample mean of stiffness data from tests. The characteristic value of structural stiffness can be calculated from the characteristic value of material stiffness in conjunction with geometry data.

5.6.3.5 As a minimum, strength and stiffness shall be documented in all the main fibre directions of a laminate. This can be done by calculations using classical laminate theory. Testing may be necessary when representative material properties are not available.

5.6.3.6 Laminate properties shall be documented for the maximum and minimum use temperature. In most cases, properties do not change much with temperature as long as the temperature remains 20°C below the glass transition temperature $T_g$. If the service temperature remains within the non-change conditions, testing at room temperature is sufficient.

5.6.3.7 For general plate calculations for thin plates, through thickness stresses are small and can be ignored as long as the general performance requirements for the laminate are met. Through thickness laminate properties need not be measured. If through thickness stresses are needed in the design calculations, their properties have to be based on values measured on the actual laminates.

5.6.3.8 Characteristic values for use in design are needed in the design phase before the production phase is initiated. Prior to the production phase, samples from the actual material used for the construction of the lifeboat are not available to allow the material properties to be determined from tests on such samples, so other means to establish the characteristic values must be resorted to. The characteristic values for the material properties can be determined based on experience of similar materials. They can also be determined from tests on specimens obtained from laminate made in advance, in which case at least five tests shall be carried out. When determining characteristic values, an extra margin may be included as deemed fitting. Such a margin may be necessary to meet the requirement for verification during production in [5.6.3.9].

Guidance note:
The coefficient of variation used for the design should be assumed with care. It is advisable to assume a conservative, large value, maybe even higher than a recommended minimum assumption of 7%, in order to make sure that the resulting sample coefficient of variation of the material during production will not be larger than the value assumed for the design.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---
5.6.3.9 In the production phase, the characteristic values of strength and stiffness used in the design shall be confirmed. This shall be accomplished by means of tests of cut-outs taken from surplus material from the construction of the actual lifeboat. A plan for testing the cut-out specimens shall be provided as early as in the design phase. The estimates of the characteristic values based on results from these tests shall be established with 50% confidence. This can be done according to the method specified in [5.6.3.2] and [5.6.3.3]. It shall be verified that these estimates do not fall short of the characteristic values used in the design. See [6.3.2].

Guidance note:
The prime purpose of the verification tests in the production phase is to detect possible gross errors during the production of the laminate structure.

5.6.3.10 For secondary structures, representative material values may be used instead of values from testing. In this case, the characteristic strength shall be taken as 80% of the representative value.

Guidance note:
Representative material values are values for material properties available from data sheets or textbooks.

5.6.3.11 If the material is exposed to long-term static loads, stress rupture or creep may be relevant. Values of representative material properties for long-term behaviour can be used in structural calculations.

5.6.3.12 Matrix cracking is an acceptable failure mechanism in a lifeboat. However, if such cracks are assumed to be present, the laminate stiffness shall be reduced to reflect the presence of these cracks.

5.6.3.13 Fatigue properties may be ignored as long as the lifeboat is designed and intended to be used only once for emergency evacuation.

5.6.4 Qualification of material

5.6.4.1 The laminate shall be suitable for use in a marine environment. In order to achieve this, the requirements given in [5.6.5] through [5.6.8] shall be fulfilled.

5.6.5 Glass fibre reinforcements

5.6.5.1 The glass is to be of E quality, where the sum of Na₂O and K₂O is to be less than 1%. A certificate showing the chemical composition shall be presented, or a chemical analysis shall be carried out to document the chemical composition. The resistance of the glass fibres to the expected environmental conditions should be made plausible.

5.6.5.2 Fibres made of other glass qualities may be used subject to special agreement and provided that their mechanical properties and hydrolytic resistance are equally good or better.

5.6.5.3 Coupling agents of silane compound or complex chromium compound are to be used.

5.6.5.4 The glass fibres shall be produced as continuous fibres. Tests of glass fibres to determine their properties shall be carried out on samples of the glass fibre product which are in the same particular form as the glass fibre product which is to be used for lifeboat manufacturing in the yard.

5.6.5.5 For roving that will be applied by spraying, a demonstration shall be performed to show that the roving is suitable for this form of application. A report from this demonstration shall be provided.

5.6.5.6 Requirements for properties of glass fibre products are given in DNV Rules for High Speed, Light Craft and Naval Surface Craft, Pt.2 Ch.4.

5.6.6 Carbon fibre reinforcements

5.6.6.1 To reduce defect sensitivity due to brittle behaviour, carbon fibre for use in load-bearing structures should have a strain to failure in excess of 1%.

5.6.6.2 The carbon fibres shall have a sizing (coupling agent treatment) that is suitable for the resin material to be used.
Guidance note:
Most carbon fibre sizing is optimized for epoxy resins. To work properly with polyester and vinylester resins, a specially formulated sizing normally needs to be used.

---end---of---guidance---note---

5.6.6.3 Tests of carbon fibres to determine their properties shall be carried out on samples of the carbon fibre product which are in the same particular form as the carbon fibre product that is to be used for lifeboat manufacturing in the yard. The laminate quality of the test specimens – in terms of resin content, void content, fibre alignment and fibre straightness – shall be representative of the intended shipyard production. The use of measured properties from a laminate with a resin content lower than that expected in the shipyard production is not permitted.

Guidance note:
Properties of carbon laminate do not necessarily improve with decreasing resin content.

---end---of---guidance---note---

5.6.7 Aramid fibre reinforcements

5.6.7.1 All aramid reinforcements are to comply with the requirements for properties given in DNV Rules for High Speed, Light Craft and Naval Surface Craft, Pt.2 Ch.4.

5.6.7.2 The laminate to be tested in interlaminar shear is to be according to [5.6.7.8] to [5.6.7.12]. The test specimen is to be oriented in a direction parallel to the majority of the fibres when possible, or in the main direction of the reinforcement.

5.6.7.3 The laminate to be tested is to be produced according to [5.6.7.7] to [5.6.7.10], and is to have a thickness of between 3 and 8 mm.

5.6.7.4 The tensile and compressive capacity of the Aramid reinforcement can be determined by testing according to recommendations given in DNV Rules for High Speed, Light Craft and Naval Surface Craft, Pt.2 Ch.4.

5.6.7.5 The laminate to be tested is to be according to [5.6.7.7] to [5.6.7.12], and the tensile tests are to be performed in the main fibre directions of a fabric/weave.

5.6.7.6 The fatigue capacity of the Aramid reinforcement can be determined by testing according to recommendations given in DNV Rules for High Speed, Light Craft and Naval Surface Craft, Pt.2 Ch.4. The laminate to be tested is to be according to [5.6.7.7] to [5.6.7.12]. The tests are to be run in load control in tension-compression, with R = -1. The static strength, $\sigma_{\text{static}}$, is the manufacturer's specified minimum value, tensile or compressive - whichever is lesser. If the requirement is not fulfilled, the static strength values have to be reduced until the fatigue condition is fulfilled.

5.6.7.7 The laminate is to be made with a marine grade polyester, vinylester, or epoxy. The manufacturer may choose the type of resin, but the testing will only be valid for the type of resin used, as well as for resins with higher tensile strength and higher elongation at failure.

5.6.7.8 It is recommended that the laminate be cured at room temperature and atmospheric pressure. However, another curing cycle may be chosen by the manufacturer. It is recommended to select a curing cycle which is feasible to accomplish in the yard.

5.6.7.9 The laminate shall have a fibre volume fraction as specified by the manufacturer of the reinforcement. It is recommended to select a fibre volume fraction which is obtainable in the yard.

5.6.7.10 When laminated, the fibre reinforcement is to have the maximum moisture content specified by the manufacturer, see [5.6.7.1].

5.6.7.11 In general, all layers of fabrics/weaves are to be oriented in the same direction in the laminate. Exceptions can be made if symmetric laminates are needed for testing. Such cases are to be discussed with the certifying body.

5.6.7.12 Test specimens are to be wide enough to cover at least four repeats of the structure of the weave/fabric.
5.6.8 Polyester and vinylester products

5.6.8.1 For polyester and vinylester, a distinction is made between the following quality grades:

— resin grade 1: quality with good water resistance
— resin grade 2: quality with normal water resistance
— fire retardant resin
— gelcoat and topcoat
— fire retardant gelcoat and topcoat.

**Guidance note:**
Resin Grade 2 is not usually used for free-fall lifeboats.

5.6.8.2 The polyester and vinylester shall be suitable for lamination using the hand lay-up, spraying, resin transfer moulding and vacuum bagging methods. They shall have good wetting properties and shall cure satisfactorily at normal room temperature, or in other specified curing conditions. Polyester and vinylester intended for other production methods may be approved after special consideration.

5.6.8.3 Requirements for the production of the resin and for quality control are given in DNV Rules for High Speed, Light Craft and Naval Surface Craft, Pt.2 Ch.4. As an alternative to these requirements, equivalent requirements in a recognized standard may be applied.

5.6.8.4 Requirements for cured resin are given in DNV Rules for High Speed, Light Craft and Naval Surface Craft, Pt.2 Ch.4. Unless otherwise specified by the manufacturer, the following curing procedure shall be used:

— standard MEKP (active oxygen 9.0 to 9.2%)
— curing: 24 hours at 23°C
— post curing: 24 hours at 50°C.

Curing systems requiring high temperature may be approved after special consideration.

5.6.8.5 Resins containing waxes and other substances, such as DCPD resins and blends of DCPD, which might lower the external adhesive capacity are to be subjected to a delamination test according to DNV Rules for High Speed, Light Craft and Naval Surface Craft, Pt.2 Ch.4. For this purpose, the preparation of the test piece shall comply with the following procedure:

— A primary laminate consisting of five (5) layers of 450 g/m² emulsion/powder bounded mat with excess polyester in the upper surface. Curing procedure: 48 hours at 23°C. The laminate surface is not to be covered.
— A secondary laminate consisting of five (5) layers of 450 g/m² emulsion/powder bounded mat is built on the first without any form of upper surface treatment.
— Curing procedure as selected in [5.6.8.4]. The fibre weight fraction is to be 50% ± 5%.

5.6.8.6 The preparation of the reference piece shall satisfy

— A laminate consisting of ten (10) layers of 450 g/m² emulsion/powder bounded mat. Curing procedure as selected in [5.6.8.4].

5.6.8.7 Polyester and vinylester can be approved as fire retardant qualities provided they comply with the following: the hull and canopy material shall be flame tested to determine its fire-retarding characteristics by placing a test specimen in a flame. After removal from the flame, the burning time and burning distance shall be measured and be to the satisfaction of the certifying body.

5.6.8.8 The finished resin in liquid condition and including all fillers shall fulfil the requirements for liquid resin and cured resin (Grade 2) as well as the combustibility requirements given in DNV Rules for High Speed, Light Craft and Naval Surface Craft, Pt.2 Ch.4.

5.6.8.9 A finished resin with water absorption of 100 to 150 mg per test sample may be approved after
special consideration. (This shall be evaluated by means of a blistering test and a test of laminate properties after aging at elevated temperature.)

5.6.8.10 Gelcoat and topcoat are to be made of base polyester that fulfils the requirements for properties given in DNV Rules for High Speed, Light Craft and Naval Surface Craft, Pt.2 Ch.4.

5.6.8.11 Fire retardant gelcoat and topcoat shall be made of base resin that fulfils the requirements for fire retardant resins in [5.6.7.7] and shall be able to withstand long-term exposure to weathering without any visible signs of crazing, outwash of matter or dramatic colour change.

5.7 Sandwich materials

5.7.1 Introduction

5.7.1.1 A sandwich structure is considered here as a lightweight core embedded between two faces (or skins). Faces are typically made of FRP laminates. The properties of laminates are described in [5.6]. This subsection concentrates on the properties of cores and the core–skin interface.

5.7.1.2 Methods described in DNV-OS-C501 may be used to calculate and document core and interface properties.

5.7.2 Sandwich specification

5.7.2.1 Laminate, core materials and adhesives used in a sandwich component shall be clearly specified and all materials shall be traceable. The laminate specification shall be given as described in [5.6].

5.7.2.2 For the core material and adhesive, a minimum set of process parameters and constituent material characterizations is given in Table 5-10 and Table 5-11. All these items shall be specified.

Table 5-10 Core specifications, process parameters and conditioning parameters

<table>
<thead>
<tr>
<th>Constituent core material(s):</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic core type (e.g. foam, honeycomb, balsa etc.)</td>
<td></td>
</tr>
<tr>
<td>Core trade name (e.g. xyz123)</td>
<td></td>
</tr>
<tr>
<td>Type of core (e.g. linear foam)</td>
<td></td>
</tr>
<tr>
<td>Type/ characteristics of microstructure</td>
<td></td>
</tr>
<tr>
<td>Core manufacturer</td>
<td></td>
</tr>
<tr>
<td>Batch number</td>
<td></td>
</tr>
<tr>
<td><strong>Process parameters:</strong></td>
<td></td>
</tr>
<tr>
<td>Laminator (company)</td>
<td></td>
</tr>
<tr>
<td>Processing method</td>
<td></td>
</tr>
<tr>
<td>Processing temperature</td>
<td></td>
</tr>
<tr>
<td>Processing pressure</td>
<td></td>
</tr>
<tr>
<td>Process atmosphere (e.g. vacuum)</td>
<td></td>
</tr>
<tr>
<td>Curing temperature</td>
<td></td>
</tr>
<tr>
<td>Post curing (temperature and time)</td>
<td></td>
</tr>
<tr>
<td>Density of the core material</td>
<td></td>
</tr>
<tr>
<td>Glass transition temperature</td>
<td></td>
</tr>
<tr>
<td><strong>Conditioning parameters:</strong></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
</tr>
<tr>
<td>Water content of the core (wet, dry)</td>
<td></td>
</tr>
<tr>
<td>Chemical environment</td>
<td></td>
</tr>
<tr>
<td>Loading rate</td>
<td></td>
</tr>
<tr>
<td>Number of specimens tested</td>
<td></td>
</tr>
</tbody>
</table>

Table 5-11 Adhesive specifications, process parameters and conditioning parameters

<table>
<thead>
<tr>
<th>Constituent adhesive material(s):</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic adhesive type (e.g. epoxy, polyester)</td>
<td></td>
</tr>
<tr>
<td>Specific adhesive type trade name</td>
<td></td>
</tr>
<tr>
<td>Specific adhesive type batch number</td>
<td></td>
</tr>
<tr>
<td>Catalyst (trade name and batch number)</td>
<td></td>
</tr>
</tbody>
</table>
5.7.2.3 The orientation of nonhomogeneous or anisotropic materials shall be clearly specified on the materials level and structural level.

5.7.2.4 The thickness of laminates and cores shall be specified.

5.7.2.5 A core layer is defined as a volume element with three axes of symmetry with respect to mechanical properties. Typically, there are two possible microstructure alignments:

— 0/90 cell alignment found in orthotropic cores. Cells run parallel to each other within the same plane. The three main directions to which material properties are referred are; width (W), length (L) and transverse (T) or the x-, y- and z-directions. Typical cores are honeycomb, balsa wood and other corrugated core.

— Random cell alignment in a quasi-isotropic core. Cells are randomly oriented without any preferred direction. A typical reinforcement type of this class is cellular foam core.

5.7.2.6 For cellular cores, i.e. wood and foam, the material behaviour and mechanical properties are considered at a macroscopic scale, i.e. material properties shall be taken from standard test specimens of a suitable size.

5.7.2.7 The measured material properties shall be measured on a scale that is compatible with the scale of general structural analyses. In regions of high local stress concentrations, the effects of local material behaviour at geometrical discontinuities shall be accounted for by component tests.

5.7.3 Strength and stiffness

5.7.3.1 Strength and stiffness shall be represented in terms of characteristic values.

5.7.3.2 The characteristic value of strength is defined as a low 2.5% quantile in the distribution of the arbitrary strength. When characteristic values of strength are estimated from data, the estimate shall be given with 95% confidence. Characteristic values can be estimated with confidence in accordance with Table 5-9. In establishing the characteristic strength of sandwich materials with balsa cores, the thickness effect on the strength of the balsa core shall be accounted for. For standard test methods, see DNV-OS-C501.

5.7.3.3 The characteristic value of material stiffness used for strength calculations is defined as the mean value. The characteristic value of material stiffness used for deflection calculations is also defined as the mean value. The characteristic value of material stiffness can be estimated by the sample mean of stiffness data from tests. The characteristic value of structural stiffness can be calculated from the characteristic value of material stiffness in conjunction with geometry data.

5.7.3.4 As a minimum, the out-of-plane shear strength and shear modulus of sandwich core materials shall be documented. To allow the analysis of core crushing at out-of-plane joints, the through-thickness compression strength shall also be documented. For details of standard test methods, see DNV-OS-C501.

5.7.4 Qualification of material

5.7.4.1 The sandwich material shall be suitable for use in a marine environment. In order to achieve this, the requirements given in [5.7.5] through [5.7.9] shall be fulfilled.

5.7.5 Sandwich core materials

5.7.5.1 Core materials shall have stable long-term properties. Continuous chemical processes, diffusion, etc., shall not affect the material’s physical properties.
5.7.5.2 On delivery, the surface of the material is normally to be such that no further machining or grinding is required to obtain proper bonding onto the material. If, however, surface treatment is required, this is to be stated by the manufacturer.

5.7.5.3 The test methods described consider most grades of closed cell polymeric foams and end grain balsa core. For core materials of a particular composition or structure, e.g. honeycombs, other requirements or additional requirements may be introduced.

5.7.5.4 Core materials are normally to be compatible with resins based on polyester, vinylester and epoxy. Core materials with a limited compatibility may be accepted following special consideration. Limitations are to be stated by the manufacturer.

5.7.5.5 The qualification of the material shall refer to a set of physical properties, which will be stated in the material certificate. The minimum properties are to be specified by the manufacturer and verified by testing. The requirements applicable for all core materials are stated in [5.7.5.6] to [5.7.5.14] and in DNV Rules for High Speed, Light Craft and Naval Surface Craft, Pt.2 Ch.4.

5.7.5.6 Density: the manufacturer is to specify a “Manufacturer’s Specified Minimum Value” (msmv) which is confirmed by the test results.

5.7.5.7 Water absorption: the two sides of the cube that face the laminate skins are to be sealed with resin. The manufacturer is to specify a “Manufacturer’s Specified Minimum Value” (msmv) which is confirmed by the test results.

5.7.5.8 Tensile properties: the tensile tests are to be performed in the through thickness direction of the core. For very anisotropic materials, the certifying body may require additional tests in other directions. The core material is to be laminated with:
- a standard ortho polyester, and/or
- a resin with better adhesion properties than standard ortho polyester. In such cases, the use of the core material will be limited to the resin type used and resins with better adhesion properties. If the selected resin is temperature sensitive, e.g. rubberized, testing at +50°C and −10°C may be needed in addition.

The resin type used is to be stated in the test report.

The laminated core may then be glued or laminated onto the test fixtures. Testing rate: the maximum speed of deformation, in mm/minute, is to be 10% of the value of the measured initial thickness. The tensile properties are to be taken as the measured value irrespective of whether the failure is in the core or in the core resin interface. Elongation shall be measured with an extensometer on the core and a secant modulus to be established.

The manufacturer is to specify a "Manufacturer’s Specified Minimum Value” (msmv) which is confirmed by the test results.

5.7.5.9 Compression testing: the compression tests are to be performed in the through thickness direction of the core. For very anisotropic materials, the certifying body may require additional tests in other directions.

The cell walls at the loaded surfaces are to be stabilized with a suitable resin. Testing rate: the maximum speed of deformation, in mm/minute, is to be 10% of the value of the measured initial thickness. Compression shall be measured with an extensometer and a secant modulus to be established.

The manufacturer is to specify a "Manufacturer’s Specified Minimum Value” (msmv) which is confirmed by the test results.

5.7.5.10 Block shear testing: the shear strength, modulus and elongation of ductile core materials are to be determined by block shear testing according to ISO 1922-81.

The shear strength, modulus and elongation are to be determined by the following method:
- The shear strength of each specimen, $\tau_{\text{fail}}$, is defined as the maximum shear stress measured and is to be determined for each specimen.
- The manufacturer’s specified minimum shear strength, $\tau_{\text{msmv}}$, is to be specified by the manufacturer, and is to be below the calculated value: mean −2 standard deviations of the individual values of the $\tau_{\text{fail}}$. 


For the purpose of determining the design shear modulus, the design shear strength, \( \tau_{\text{design}} \), is defined as 0.3 \( \tau_{\text{msmv}} \).

The “0.3 shear elongation”, \( \gamma_{0.3 \tau_{\text{design(i)}}} \), is defined as the elongation corresponding to \( \tau_{\text{design}} \), and is to be taken from the measured stress-strain curve for each specimen.

The “average 0.3 shear elongation”, \( \gamma_{0.3 \tau_{\text{design average}}} \), is defined as the mean of the individual \( \gamma_{0.3 \tau_{\text{design(i)}}} \) values.

The design shear modulus is defined as:

\[
G_{\text{design}} = \frac{\tau_{\text{design}}}{\gamma_{0.3 \tau_{\text{design average}}}}
\]

5.7.5.11 Four-point bend shear testing of a sandwich with ductile core material: in order to ensure that the tensile strength of the core and core/skin interface is proportionate to the shear strength, the core variant with the highest density within each grade is to be tested in a four-point bend according to ASTM C393-88.

Scored core material of the highest density variant and greatest thickness delivered is to be laminated with the following lay-up:

- 200 g/m² CSM at the core skin interface
- subsequent layers of 800/100 g/m² WR/CSM combimat or 200 g/m² CSM.

The total thickness of each skin laminate is not to exceed 10% of the core thickness. The fibre weight fraction is to be 50% ± 5%.

The manufacturer may elect to use:

- a standard ortho polyester, and/or
- a resin with better adhesion properties than standard ortho polyester. In such cases, the use of the core material will be limited to the resin type used and resins with better adhesion properties. If the selected resin is temperature sensitive, e.g. rubberized, testing at +50°C and −10°C may be needed in addition.

The resin type used is to be stated in the test report.

The manufacturer may elect to fill the scores with resin or a sandwich adhesive. In this case, the filling of the scores will be a condition of use.

The shear strength obtained from the four-point bend test, calculated according to [5.7.5.10], is to confirm the data from the block shear testing.

If the shear strength value obtained from the four-point bend test is lower than the value obtained from the block shear testing, the manufacturer may elect to:

- retest with another resin, or
- the obtained value will be used. The shear modulus calculated according to [5.7.5.10] is to be based on the new shear strength. In such cases, the core variant with the next-largest density is to be tested in the same manner.

5.7.5.12 Four point bend shear testing of a sandwich with brittle core material: the shear strength of brittle core materials shall be obtained from four-point bend tests. The design shear strength shall be established for the core thickness to be used. Unless testing is performed for each core thickness intended to be used, the shear strength of end grain balsa shall be corrected for the effect of thickness by multiplying the shear strength obtained for a thickness of 50 mm by the factor \( f_c \):

\[
f_c = \left( \frac{50}{c} \right)^{0.27}
\]
where $c$ is the core thickness of the actual panel being analysed (mm). The shear strength shall be corrected for the effect of the panel size by multiplying the shear strength obtained as described above by the factor $f_{ib}$

$$f_{ib} = \left(\frac{1.6}{a}\right)^{0.25}$$

where $a$ is the smaller of the panel dimensions (m) and $f_{ib}$ shall be equal to 1.0 for $a \leq 1.6$ m.

5.7.5.13 The heat resistance temperature is defined as the temperature at which either the:

- shear strength or
- shear modulus

has decreased by 20%.

The heat resistance temperature is to be specified by the manufacturer and is to be greater than +45°C. The heat resistance temperature is to be confirmed by four-point bend testing the highest density core at the specified temperature according to [5.7.5.11], where the shear strength and modulus are to be > 80% of the results obtained in [5.7.5.10].

5.7.5.14 Sufficient water resistance shall be confirmed after conditioning in salt water (DIN 50905) at 40°C for four weeks – by four-point bend testing of the highest and lowest density variant according to [5.7.5.11], where the shear strength and modulus are to be > 80% of the results obtained in [5.7.5.11].

5.7.6 Core material in areas exposed to slamming

5.7.6.1 The requirements applicable to core material to be used in areas exposed to slamming are given in [5.7.6.2] to [5.7.6.7]. The material certificate shall state whether or not the material properties with respect to slamming have been determined.

Guidance note: In free-fall lifeboats, most of the fore, aft and bottom areas are expected to be exposed to slamming.

5.7.6.2 Scored core material of the lowest and highest density variant and greatest thickness delivered is to be tested in a four-point bend according to ASTM C393-88, at a high loading (i.e. slamming) rate.

5.7.6.3 The sandwich beam is to include a longitudinal adhesive joint between two core material planks. The qualification of the material is valid for the adhesive used and for adhesives with greater shear elongation at 0°C. The adhesive type used is to be stated in the test report.

5.7.6.4 The core material is to be laminated with the following lay-up:

- 200 g/m² CSM at the core skin interface
- subsequent layers of 800/100 g/m² WR/CSM combimat or 200 g/m² CSM.

The total thickness of each skin laminate is not to exceed 10% of the core thickness. The fibre weight fraction is to be 50% ± 5%. The manufacturer may elect to use:

- standard ortho polyester, and/or
- a resin with better adhesion properties. In such cases, the use of the core material will be limited to the resin type used and resins with better adhesion properties. If the selected resin is temperature sensitive, e.g. rubberized, testing at +50°C and -10°C may be needed in addition.

The resin type used is to be stated in the test report.

5.7.6.5 The manufacturer may elect to fill the scores with resin or a sandwich adhesive. In such case, this is to be stated.

5.7.6.6 The beam is to be loaded at a rate of $d\tau/dt = 65$ MPa s⁻¹.

5.7.6.7 The shear strength obtained from the four-point bend test at the slamming rate is to confirm the data from the block shear testing determined in [5.7.5.10].
5.7.7 Sandwich adhesives

5.7.7.1 For sandwich adhesives, a distinction is made between two different quality grades:

Grade 1: quality of sandwich adhesives required for hull structures.
Grade 2: quality of sandwich adhesives required for less critical applications than hull structures.

Guidance note:
Grade 1 is used for structures and components categorized as primary. Grade 2 is used for structures and components categorized as secondary.

5.7.7.2 The qualification of the material will refer to a set of physical properties. The minimum properties shall be specified by the manufacturer and verified by testing. The properties to be documented in the test report are specified in DNV Rules for High Speed, Light Craft and Naval Surface Craft, Pt.2 Ch.4 together with acceptance criteria.

5.7.7.3 Requirements for the production of the adhesive and quality control are given in DNV Rules for High Speed, Light Craft and Naval Surface Craft, Pt.2 Ch.4.

5.7.7.4 Requirements for cured material in the joint are given in DNV Rules for High Speed, Light Craft and Naval Surface Craft, Pt.2 Ch.4.

5.7.7.5 Curing conditions are to be according to the manufacturer’s specifications, preferably at temperatures obtainable in a yard. A detailed description of the surface treatment and application procedure is required.

5.7.7.6 The heat resistance temperature is defined as the temperature at which the flatwise tensile strength has decreased to 80% of the room temperature strength.

The heat resistance temperature is to be specified by the manufacturer and is to be greater than +45°C. The heat resistance temperature is to be confirmed by testing according to flatwise tensile testing at the specified temperature, where the flatwise tensile strength is to be at least 80% of the results obtained at room temperature.

For testing of shear and flatwise tension, the test samples are to be made of two pieces of high density core material (preferably PVC foam), with the sandwich adhesive located in the mid-plane parallel to the steel supports. The adhesive layer is to be more than 1 mm thick.

5.7.8 Adhesives

5.7.8.1 Stress patterns in adhesive joints are highly sensitive to joint geometry, so the performance of an adhesive is highly dependent on the type of joint. General requirements for the adhesive that are valid for all joint geometries cannot therefore be given.

5.7.8.2 The requirements in this subsection provide:
— the acceptance criteria for allowable degradation when loaded in a marine environment
— a method for determining basic mechanical performance data.

5.7.8.3 The design of each joint is to be evaluated during the approval of classed objects.

5.7.8.4 If one of the adherends is glass subject to sunlight, a ceramic coating is to be applied to effectively block the UV radiation. If a joint is loaded in fatigue, impact, etc., further testing may be required.

5.7.8.5 Information regarding the incompatibility of the adhesive’s curing system with other curing systems or chemicals, and the cured adhesive’s possible lack of chemical resistance to oils, detergents, etc., is to be submitted by the adhesive manufacturer.

5.7.8.6 The following properties shall be considered when testing and applying adhesives to lifeboat structures:
— mixing ratio
— pot life/open time
— range of temperature
— range of humidity
— range of temperature over dew point
— range of maximum and minimum thicknesses of adhesive joints.

5.7.8.7 The adhesive shall be tested with each adherend that it is to join. The tests shall be carried out according to the test methods stated in DNV Rules for High Speed, Light Craft and Naval Surface Craft, Pt.2, Ch.4, with each adherend that the adhesive is to join. Aluminium of different series is to be tested if applicable.

5.7.8.8 Lap-shear strength: the manufacturer is to specify a “Manufacturer’s Specified Minimum Value” (msmv) for the lap-shear strength, measured according to the applicable standard, which is to be confirmed by the test results. The manufacturer can choose to specify an msmv value less than “mean –2 sdev”.

5.7.8.9 Fracture strength in cleavage: the manufacturer is to specify an msmv for the fracture strength in cleavage, measured according to ASTM D3433-93, which is to be confirmed by the test results.

5.7.8.10 Glass transition temperature: the glass transition temperature (Tg.) of the adhesive is to be determined according to ASTM D1356-91.

5.7.8.11 Minimum toughness: the toughness of the adhesive system (including the adherends and their surface treatment) shall be sufficient to prevent undue sensitivity to unforeseen local peel stresses or other unfavourable modes of loading. This may be deemed fulfilled if the fracture toughness of the adhesive system established according to DNV Rules for High Speed, Light Craft and Naval Surface Craft, Pt.2 Ch.4 exceeds the minimum value specified there. The specimens shall be prepared with adherends of the materials intended to be bonded with sufficient stiffness and strength to produce a fracture of the bondline (see guidance given in [5.6.8.5]) and with the surfaces to be bonded prepared under realistic conditions according to the surface preparation process used at the shipyard.

5.7.9 Expanding foam

5.7.9.1 When accounted for in the structural design, expanding foam materials shall show stable long-term properties and continuous chemical processes, diffusion, etc., shall not affect the physical properties of the material.

5.8 Manufacturing of FRP structures

5.8.1 General

5.8.1.1 There are limited or no means available for nondestructive examination of structural components constructed from composite materials and sandwich materials. Therefore, the safety targets specified in this standard can only be met if both the design is carried out according to the prescriptions of this standard and there is rigorous control of all the fabrication steps to ascertain that the finished product complies with the specifications.

5.8.1.2 The quality assurance system to be implemented by the manufacturer as required in [1.1.3.4] shall be formalized in the form of a quality handbook or a similar document including, but not limited to, the following main subjects:

— organization of all quality-related activities
— identification of key personnel and their responsibilities
— documentation procedures
— qualification of personnel
— manufacturing conditions, including the recording of temperature and humidity
— receipt and storage of raw materials
— working procedures and instructions
— formulation of resins
— lamination records
— procedures for quality control and inspection or testing
— repair procedures
— defect acceptance criteria.

5.8.2 Storage

5.8.2.1 Storage premises shall be so equipped and arranged that the material supplier’s directions for the storage and handling of the raw materials can be followed.

5.8.2.2 Storage premises for reinforcement materials shall be kept dry and clean so that the raw material is not contaminated. The materials shall be stored in unbroken original packaging before being used. Materials whose original packaging has been broken shall be adequately protected against contamination when stored again after use.

5.8.2.3 Reinforcement materials shall normally be stored at the same temperature and humidity as those prevailing in the workshop where the materials are going to be used. If the storage temperature is not the same, the material shall be acclimatized at the workshop temperature and humidity prior to being deployed. The period of acclimatization shall be adequate for the amount of reinforcement: for unbroken packages, the acclimatization period shall be at least two days.

5.8.2.4 Resins, gelcoat, hardeners, additives, etc., shall be stored according to the manufacturer’s recommendations regarding temperature, shelf life, etc. Raw materials which are stored at temperatures lower than +18°C shall be acclimatized to the temperature of the workshop prior to being used. Tanks for resins, etc., shall be handled during storage according to the manufacturer’s recommendations and shall be equipped and arranged accordingly.

5.8.2.5 Core materials shall be stored dry and protected against contamination and mechanical damage. Core materials shall normally be stored at the same temperature as that in the workshop where the materials are going to be used. If the storage temperature is not the same, the material shall be acclimatized at the workshop temperature and humidity prior to being deployed.

5.8.2.6 Core materials shall be stored in such a way that outgassing of the materials is ensured before the materials are used. Outgassing shall be carried out according to the manufacturer’s recommendations. When new free surfaces are created in the material, e.g. by sanding, cutting or machining, proper outgassing shall be ensured once again.

5.8.2.7 Pre-pregs shall be stored according to the manufacturer’s recommendations. For pre-pregs stored in refrigerated conditions, a log shall be kept for each package showing the period for which, and at which temperature, the package has been stored or used outside of its normal storage conditions.

5.8.3 Manufacturing premises and conditions

5.8.3.1 Manufacturing premises shall be so equipped and arranged that the material supplier’s directions for handling the materials, the laminating process and curing conditions can be followed.

5.8.3.2 The manufacturing premises shall be free from dust and other contamination that may in any way impair the quality of the end product.

5.8.3.3 The air temperature in the moulding shops is not to be less than +18°C. The stipulated minimum temperature is to be attained at least 24 hours before commencement of lamination and is to be maintainable regardless of the outdoor air temperature. The temperature in the moulding shop is not to vary more than ±5°C. This limit can be exceeded provided it has no detrimental effect on the product and there is no risk of condensation of humidity.

5.8.3.4 The relative humidity of the air shall be kept so uniform that condensation is avoided. Unless an adequate margin against the risk of condensation of humidity is provided, the relative humidity shall not exceed 80%. In areas where spray moulding is taking place, the air humidity shall not be less than 40%. The stipulated air humidity shall be maintainable regardless of the outdoor air temperature and humidity. More stringent humidity requirements shall be adhered to if recommended by the manufacturer.

5.8.3.5 Other manufacturing conditions may be acceptable provided it is documented that condensation of humidity can be safely avoided.
5.8.3.6 The air temperature and relative humidity shall be recorded regularly and the records filed for a period of at least two years. In larger shops, there is to be at least one thermohydrograph for each 1500 m² where lamination is carried out. The location of the instruments shall be such as to give representative measurement results.

5.8.3.7 Draughts through doors, windows, etc., and direct sunlight are not acceptable in places where lamination and curing are in progress.

5.8.3.8 The ventilation plant shall be so arranged that the curing process is not negatively affected.

5.8.3.9 Sufficient scaffoldings shall be arranged so that all lamination work can be carried out without operators standing on the core or on surfaces on which lamination work is taking place.

5.8.3.10 During the lamination of larger constructions, the temperature should be recorded on at least two vertical levels in the workshop and the curing system should be adjusted to compensate for possible temperature differences.

5.8.3.11 The prefabrication of panels and other components shall be carried out on tables, fixtures, etc., above the shop floor level. No fabrication shall be carried out on the shop floor.

5.8.4 Production procedures and workmanship

5.8.4.1 The supplier’s directions for the application of the materials are to be followed.

5.8.4.2 Specified procedures shall be implemented for all tasks of significance to the quality of the end product. Where necessary to exercise satisfactory control of the quality, these procedures shall be documented in writing in controlled documents.

5.8.4.3 After the reinforcement is laid, its reference direction shall not deviate from that specified by more than ±5°.

5.8.4.4 Adjacent sheets of reinforcement shall normally overlap to provide structural continuity. The overlap length shall be such that the shear capacity of the overlap is not less than the tensile strength (perpendicular to the overlap) of the overlapping plies. Unless otherwise agreed, the shear strength of the matrix shall not be assumed to be larger than 8 MPa. (For example, for a 0/90° 1000 g/m² type glass reinforcement, the overlap shall not be smaller than 30 mm.) In areas of low utilization, overlaps may be omitted subject to agreement. Overlaps shall be staggered through the thickness of the laminate. The distance between two overlaps in adjacent plies shall not be smaller than 100 mm.

5.8.4.5 Thickness changes in a laminate should be tapered over a minimum distance equal to 10 times the difference in thickness.

5.8.4.6 Thickness changes in core materials should be tapered over a minimum distance equal to twice the difference in thickness. A larger distance may be required to maintain the structural continuity of the skins.

5.8.4.7 Sandwich constructions can be fabricated by either lamination on the core, application of the core against a wet laminate, bonding of the core against a cured skin laminate using a core adhesive, resin transfer, or resin transfer moulding of the core together with one or both of the skin laminates.

5.8.4.8 An efficient bond shall be obtained between the skin laminates and the core and between the individual core elements. The bond strength shall not be less than the tensile strength and shear strength of the core. The application of a light CSM between the core and skin laminate may be advantageous in this respect.

5.8.4.9 Approved tools for cutting and grinding various types of core material shall be specified in the production procedure.

5.8.4.10 All joints between the skin laminates and core and between the individual core elements shall be completely filled with resin, adhesive or filler material. The joint gap between core blocks should generally not be larger than 3 mm. Larger gaps may be acceptable, based on an evaluation of the characteristics of the adhesive or filler (e.g. its viscosity) and the thickness of the core. For areas exposed to slamming, a larger gap width should be reflected in the qualification testing of the core material and the adhesive, i.e. during slamming testing, see [5.7.6].
5.8.4.11 Core materials with open cells in the surface should normally be impregnated with resin before being applied to a wet laminate or before lamination on the core commences.

5.8.4.12 When the core is applied manually to a wet laminate, the surface shall be reinforced with a chopped strand mat of 450 g/m² in plane surfaces and 600 g/m² in curved surfaces. If a vacuum is applied for core bonding, the surface mats may be omitted provided the qualification tests demonstrate that an efficient bond is obtained between the core and skin laminate.

5.8.4.13 If the core is composed of two or more layers of core material and any form of resin transfer is used, arrangements shall be made to ensure proper resin transfer and filling between the core blocks. This should be achieved by scoring or holing the core blocks and placing a reinforcement fabric between the core blocks to facilitate resin distribution.

5.8.4.14 Frameworks for core build-up shall give the core sufficient support to ensure a stable geometrical shape of the construction and a rigid basis for the lamination work.

5.8.4.15 When a prefabricated skin laminate is bonded to a sandwich core, measures are to be taken to evacuate air from the surface between the skin and core.

5.8.4.16 The core material is to be free from dust and other contamination before the skin laminates are applied or core elements are glued together. The moisture content shall be low enough not to have any adverse effect on curing. The acceptable moisture content shall be specified by the manufacturer of the core material.

5.8.4.17 When vacuum-bagging or similar processes are used, it shall be ensured that curing in the core adhesive has not been initiated before the vacuum is applied.

5.8.5 Manual lamination

5.8.5.1 The reinforcement material shall be applied in the sequence stated on the approved plan(s).

5.8.5.2 When the laminate is applied in a mould, a chopped strand mat of maximum 450 g/m² is to be applied next to the gelcoat. The mat can be omitted provided satisfactory resistance to water can be ensured.

5.8.5.3 The resin shall be applied on each layer of reinforcement. Gas and air pockets shall be worked out of the laminate before the next layer is applied. The layers shall be rolled carefully, paying special attention to sharp corners and transitions. The resin's viscosity and gel-time shall be adequate to prevent drain-out of the resin onto vertical and inclined surfaces. The tools and methods used when working the laminate shall not damage the fibres.

5.8.5.4 The time interval between the applications of each layer of reinforcement shall be within the limits specified by the resin supplier. For thicker laminates, care shall be taken to ensure a time interval sufficiently large to avoid excessive heat generation.

5.8.5.5 Curing systems shall be selected with due regard to the resin's reactivity and in accordance with the supplier's recommendations. Heat release during curing shall be kept at a safe level in accordance with the material manufacturer's recommendations. The quantity of curing agents shall be kept within the limits specified by the supplier.

5.8.5.6 After completion of lamination, polyester laminates shall cure for at least 48 hours at an air temperature of minimum +18°C. Curing at a higher temperature and for a shorter time may be accepted on the basis of control of the curing rate. For other types of resins, curing shall be carried out according to the specified cure cycle and according to the resin manufacturer's recommendations.

5.8.6 Core vacuum-assisted resin transfer moulding and vacuum bagging

5.8.6.1 Points of resin injection shall be located and opened and closed in a sequence that ensures the complete filling of the mould without any air being trapped.

5.8.6.2 The resin shall be formulated, based on the resin manufacturer's recommendations, such that an adequate viscosity and gel-time are obtained to enable filling of the complete mould and such that the maximum temperature during curing is kept within acceptable limits, e.g. with respect to the temperature sensitivity of core materials.
5.8.6.3 The pressure level (vacuum) in the mould shall be specified prior to infusion. The pressure shall be sufficient to ensure that the consolidation of the laminate is adequate, that the specified mechanical properties are achieved and that the mould is properly filled. The pressure shall be maintained throughout the mould during the laminate’s cure cycle, or at least past the point of maximum temperature in the laminate, and the specified hold time. The vacuum shall be monitored by the use of pressure gauges distributed throughout the mould such that a reliable indication of the pressure distribution is obtained. This means that pressure gauges shall be placed far away from vacuum suction points. An adequate means to locate and repair leakage shall be deployed.

5.8.7 Curing

5.8.7.1 Cure cycles shall be documented by temperature records.

5.8.7.2 For curing that takes place at room temperature in the workshop, the registrations made in the workshop are sufficient to document the cure cycle.

5.8.7.3 For curing at an elevated temperature, fans with ample capacity shall operate in the compartment in which the cure is carried out, thereby ensuring an even distribution of temperature. Continuous records of the temperatures throughout the cure cycle shall be obtained. Recording points shall be distributed throughout the length, width and height of the cure compartment to the extent necessary to verify that the temperature distribution is even.

5.8.8 Secondary bonding

5.8.8.1 A secondary bonding is defined as any bond between two FRP structures which is made after one or both of the individual structures has effectively cured.

5.8.8.2 The surface ply of a laminate subject to secondary bonding and the first ply of the bonding laminate are normally to consist of chopped strand mat. This mat can be dispensed with provided the necessary bond strength is reached.

5.8.8.3 Surfaces in way of secondary bonding are to be clean and free from dust and other forms of contamination.

5.8.8.4 Laminates on which secondary bonds are to be carried out shall have an adequate surface preparation, normally including grinding.

5.8.8.5 If “peel strips” are used in the bonding surface, the required surface treatment may be waived provided an adequate bond strength is documented.

5.8.9 Adhesive bonding

5.8.9.1 Adhesive bonding shall be carried out according to the same procedure(s) that the design and qualification testing has been based on, see Sec.9, and according to the recommendations from the adhesive’s manufacturer. The procedure(s) shall give clear requirements for all factors that can affect the quality of the bond. As a minimum, the following shall be covered: the working conditions, surface preparation, application, clamp-up and curing cycle.

5.8.10 Quality assurance

5.8.10.1 The manufacturer shall have implemented an efficient quality assurance system to ensure that the finished product meets the specified requirements. The person or department responsible for the quality assurance shall have clearly established authority and responsibility and be independent of the production departments.

5.8.10.2 The system shall be formalized through a quality handbook or similar document that at least contains the following main objects:

- organization of all quality-related activities
- identification of key personnel and their responsibilities
- documentation procedures
— qualification of personnel
— manufacturing conditions, including the recording of temperature and humidity
— receipt and storage of raw materials
— working procedures and instructions
— formulation of resins
— lamination records
— procedures for quality control and inspection or testing
— repair procedures
— defect acceptance criteria.

5.8.11 Quality control

5.8.11.1 A written quality plan shall be established for the production of each hull and superstructure. The quality plan shall be fully implemented prior to the production work commencing.

5.8.11.2 The quality plan shall at least address the following items:

— relevant specifications, rules, statutory requirements etc.
— drawings
— list of raw materials
— procedures for handling raw materials
— manufacturing procedures and instructions
— procedures for keeping and filing lamination records
— procedures for keeping and filing cure logs: temperature and vacuum (for vacuum-assisted resin transfer moulding (VARTM))
— procedures for quality control and inspection or testing
— inspection points
— witness points by independent surveyor as appropriate
— production testing of laminates, joints and panels in accordance with [5.6]
— procedures for corrective actions when deficiencies are identified.

5.8.11.3 The quality plan may contain copies of all the necessary documentation and it may refer to documents in the quality handbook and other controlled documents. The relevant drawings may be identified by a list of drawings.
SECTION 6  STRUCTURAL DESIGN

6.1  General principles

6.1.1  Application

6.1.1.1  This section gives provisions for checking the ultimate, accidental and serviceability limit states for free-fall-lifeboat structures and launching systems.

6.1.2  Phases

6.1.2.1  The design life shall be divided into phases, i.e. well defined periods within the life span of the lifeboat. All phases that could influence the design of the product shall be considered.

6.1.2.2  Normally, the following phases should be considered:

- construction
- installation
- stowage
- exercise launches and retrieval
- launch
- sailing
- rescue.

A decommissioning phase may also be specified. It may be convenient to split the design life into more detailed phases, including maintenance phases.

6.1.3  Functional requirements

6.1.3.1  The lifeboat's structure and arrangements shall satisfy the functional requirements given in [6.1.3.2] to [6.1.3.11].

6.1.3.2  The lifeboat's hull structure shall comprise a watertight barrier between the lifeboat's exterior and the lifeboat's occupants and maintain the watertight integrity throughout all phases. In maintaining the watertight integrity, this barrier shall reliably resist the external pressures that act on it throughout all phases.

6.1.3.3  The structure's response shall not cause injuries or fatalities among the occupants. Hence, deflections must be within specified limits such that the deformed structure does not strike the occupants, and the noise levels and pressure changes due to the dynamic deformations, e.g. local buckling or snap-through, must be within acceptable levels that do not cause hearing injuries.

Guidance note:
Noise from dynamic deformations is not normally a problem for lifeboats with a conventional hull form and construction, but may need special consideration for lifeboats with an unusual construction, e.g. lifeboats with very flexible areas in the hull and lifeboats with an unusual hull form.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

6.1.3.4  The structure's response shall not destroy or hinder the intended use of components that are needed to maintain the safe use and operation of the lifeboat. Hence, maximum deflections must be within specified limits such that the deformed structure does not strike such components, e.g. puncture buoyancy elements or open doors or hatches, and any permanent deformations shall not hinder the operation of doors, hatches or any other safety-critical on-board system.

6.1.3.5  The structure shall be so designed as to maintain the specified level of safety at least for the lifeboat's specified service life considering the intended use of the lifeboat and the anticipated environmental exposure.

6.1.3.6  The structure's response shall not destroy components that are needed to maintain comfort on board or that will require repair afterwards, such as nonstructural bulkheads or other internal structure not contributing to the integrity of the hull.
6.1.3.7 Arrangements shall be provided in the hull structure to allow occupants to enter the lifeboat safely and efficiently according to the requirements of [7.2.2].

6.1.3.8 Arrangements shall be provided in the hull structure to allow occupants to be safely rescued from the lifeboat as set out in [7.5.6].

6.1.3.9 Arrangements shall be provided in the hull structure to provide support for on-board systems and equipment. Regarding the occupants' seats, see [8.2.8.8].

6.1.3.10 The structure of the launching system shall allow the lifeboat to be launched safely in all conditions, observing [7.3.1] and specific requirements in [6.1.8].

6.1.3.11 It shall be possible to secure hatches in the open position.

6.1.4 Premises for structural design

6.1.4.1 It is a basic premise for the structural design requirements provided in this section that the structure has good resistance to the propagation of fractures in the governing load cases.

6.1.4.2 Ductility is a mechanism that contributes to the fracture resistance in metals. Hence, ductility of the metallic materials is important for the safety of metallic structures.

6.1.4.3 Composites have good fracture resistance without much ductility because the inhomogeneous fibrous character of composites inherently provides a high fracture resistance across the fibres. The keys to translate this fracture resistance to the fracture resistance of the built-up laminates and the entire structure are to properly arrange the directions of fibre reinforcement considering the relevant stress states and otherwise to follow the principles of good composite design practice.

6.1.4.4 The fracture resistance in composite structures is an inherent property of well-designed fibrous composite laminates. Hence, for composite structures, fracture resistance requirements are given in terms of requirements that ensure a proper arrangement of fibre reinforcement and load-carrying members. These requirements are given in [6.3].

6.1.5 Structural design principles

6.1.5.1 The watertight barrier normally consists of monolithic plates of metallic or composite material or sandwich panels. During operation, all apertures shall be sealed by watertight doors, hatch covers or windows.

6.1.5.2 The plating forming the watertight barrier shall be appropriately supported by internal structure.

6.1.5.3 The design shall be robust, in terms of capacity and redundancy, for all global and local response modes.

6.1.5.4 Each structural member of a particular order in a plate–stiffener–girder–bulkhead hierarchy shall be properly supported at the next-order member in the hierarchy. Stiffeners oriented in the chosen main stiffening direction shall be carried continuously through supporting members. Figure 6-1 shows an example where longitudinal stiffeners are supported by web frames.
6.1.5.5 A system of continuous transverse frames shall be fitted which, together with other support members, supports the entire hull cross section (including the roof). If intermediate frames are fitted, their ends should be well tapered or connected to local panel stiffening.

6.1.5.6 Thrust bearings and supports should be strengthened to take the local loads.

6.1.5.7 A centre girder is to be fitted to provide a strong support if the external keel or bottom shape does not provide sufficient strength and stiffness.

6.1.5.8 Openings shall, wherever necessary, be compensated to properly counteract the effects of shear loadings.

6.1.5.9 Main engines shall be supported by longitudinal girders. The girders shall have suitable local reinforcement to support both the engine and the gearbox mounting structure.

6.1.6 Design loads

6.1.6.1 The hull structure shall be assessed by subjecting a theoretical model of the hull structure to a series of load cases which are representative of the loads that may occur in all phases of the intended life of the lifeboat and which govern the design of the structure. These load cases shall be used to produce reliable predictions of the governing load effects occurring in the structure.

6.1.6.2 Depending on the lifeboat design, the pressure distributions can be established by simple theoretical models, numerical simulations, model-scale tests, full-scale tests or a combination of these according to Sec.4.

6.1.6.3 One approach is to establish the pressure distribution on the hull as a function of time for all relevant scenarios and perform stepwise load effect analyses for each scenario.

6.1.6.4 Instead of this comprehensive approach, a limited number of idealized loading cases may be defined that are deemed representative of the critical loadings with respect to each structural element of the hull. The number of load cases needed depends on the accuracy required. Conservative assumptions are normally required unless a large number of loading cases is specified. The load cases shall consider all the relevant phases of the launches in all relevant conditions according to the provisions of Sec.4 and reflect an adjustment deemed necessary by sound engineering judgment based on the results of model and full-scale tests according to Sec.9.

6.1.6.5 Local structural elements such as plates, secondary stiffeners and sandwich panels shall be designed to resist extreme local pressures occurring when the lifeboat penetrates the sea surface. If these local pressures decay quickly compared to the build-up of other external pressures, these local loads need not be combined with other loads.
6.1.6.6 Windows, doors and hatch covers shall be designed to resist the local pressures acting on them. The collapse of the air pocket behind the lifeboat in the ventilation phase shall in particular be considered in the design of entry doors located astern. If windows, doors or hatches are supported on a protrusion from the hull, such as a deckhouse, the pressure from the protrusion entering the sea surface and from the passage of a ventilation boundary shall be considered.

6.1.6.7 Transverse frames will respond to the pressure distributed around the circumference of the hull at the section where the frame is located. The design load cases should represent the most unfavourable pressure distribution. This distribution may differ between different parts of the frame. Furthermore, the variation of pressure around the circumference combined with the predominantly compressive loading it produces in the frame may challenge the buckling resistance of the frames, cause a geometrically nonlinear response and produce snap-through effects, particularly in the roof. To assess this, the difference in pressure from the sides to the roof should be explicitly represented and the sequence of building up pressure in different areas should be accounted for.

6.1.6.8 If transverse frames are supported by longitudinal girders, full or partial bulkheads or other supporting elements, the combined response of the supports and adjacent frames needs to be considered. In that case, the longitudinal distribution of the pressures along the hull needs to be reliably represented by the design load cases considered.

6.1.6.9 Supports for heavy items such as engine foundations and seat attachments shall be designed for the maximum accelerations that occur during launches. These accelerations shall consider all the relevant phases of launches in all relevant conditions according to the provisions of Sec.4 and reflect any adjustment deemed necessary by sound engineering judgement based on the results of model and full-scale tests carried out according to Sec.9. Normally, the highest accelerations occur in the water entry phase where the slamming pressures cause high vertical and rotational accelerations of the hull. The highest accelerations can also occur at maximum submersion. To obtain a robust design that is not sensitive to deviations from the launch conditions assumed in tests and simulations, it is recommended that supports are designed for the maximum accelerations occurring in any direction rather than using different acceleration levels in the different coordinate directions.

6.1.7 Structural analysis

6.1.7.1 The ultimate strength capacity at material level (metal yield, FRP rupture, core fracture) and at structural level (buckling, collapse) shall be assessed for all structural elements based on a rational and justifiable engineering approach. FEM can be used for this purpose. Guidance the for the execution of FEM analyses is given in App.B.

6.1.7.2 Calculation methods other than FEM can be used provided the underlying assumptions are in accordance with generally accepted practice, or in accordance with sufficiently comprehensive experience or tests. However, due to the typical geometry of lifeboats, the structural capacity normally needs to be checked in the relevant load cases using general 3D structural analyses.

6.1.7.3 The structural analysis may be carried out as a linear elastic analysis provided it is documented that significant geometrically nonlinear effects do not occur. However, due to the predominantly compressive response in the hull shell and framing system, the typical cross sectional geometries of lifeboats and the typical non-uniform pressure distributions, a geometrically nonlinear analysis will normally be needed.

6.1.7.4 The structural analysis should take account of structural dynamics that significantly affect the stresses and deformations in the structure. In assessing whether dynamics in the structure are significant, consideration should be given to the duration of the transient loading, the area over which it acts and the natural vibration frequencies of the parts of the structure that would be excited by the loading considered (plates, stiffeners, frames, hull girder etc.). Simplified methods can be used to estimate of dynamic amplification factors (DAF) based on the duration of the transient loading and on the natural frequencies, and including added mass effects.

6.1.7.5 Outfitting and attachment of items in the passenger cabin shall be so designed as to ensure that no fixed items come loose from their supports considering the accelerations that may occur at that position. For each potential failure mode of the attachments, accelerations in the most unfavourable directions shall be considered. Bonded joints in composite structures shall satisfy [6.3.7]. Bolted joints in composite structures shall satisfy [6.3.8] as applicable.
6.1.7.6 The deflections of the structure shall nowhere cause the free clearance to seated passengers and crew to fall below 10 cm laterally and 20 cm overhead. The person size shall according to Sec.8 be assumed as follows:

Height from seat pan to top of head: 108 cm
Shoulder width (50% on each side of the centre line): 53 cm

6.1.8 Launching system

6.1.8.1 The structural strength and stiffness of any skid and its supports shall be sufficient to prevent the lifeboat from derailing considering all the relevant trim and list angles and accelerations of the host as well as wind forces acting on the lifeboat.

6.1.8.2 It shall be demonstrated that the launch release mechanism for the primary and secondary means of launching can be operated effectively when subject to the requirements given in NORSOK R-002 Annex A.

6.1.8.3 The structural strength of the primary means of launching shall be designed for the requirements given in NORSOK R-002 Annex A. Additional load effects resulting from the trim and list angles and accelerations of the host facility, as well as wind forces acting on the lifeboat, shall be taken into consideration.

6.1.8.4 The structural strength of the secondary means of launching and the means of retrieval shall be designed for the requirements given in NORSOK R-002 Annex A. Additional load effects resulting from hoisting and lowering movements, offlead and sidelead angles, as well as wind forces acting on the lifeboat, shall be taken into consideration.

6.1.8.5 The structural strength of the release system and the means of retrieval, including the release hook and the connection to the lifeboat (e.g. a bonded or bolted joint), shall be designed for the requirements given in NORSOK R-002 Annex A. The design load effect to be applied for this purpose shall include possible dynamic amplifications. For the determination of a relevant dynamic amplification factor, see NORSOK R-002.

Guidance note:
For means of retrieval, dynamic amplifications due to pick-up from the sea are relevant and need to be considered. Methods used for offshore cranes to lift cargo from the moveable deck on service vessels can be applied for this purpose.

For a means of retrieval intended for use also as a secondary means of launching, dynamic amplifications will most likely be dominated by the reaction forces at emergency braking.

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6.1.9 Fire

6.1.9.1 The lifeboat structure shall be protected against fire to such an extent that the criterion given in [8.4.1.1] can be met.

Guidance note:
For metallic structures, the development of excessive temperatures inside is the main problem, such that proper insulation of the lifeboat structure becomes a major issue. For composite structures, the fire resistance of the composite materials is a major issue. See DNVGL-OS-D301 and DNV-OS-C501.

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6.1.10 Ice accretion

6.1.10.1 For lifeboats to be operated from host facilities where ice accretion may occur, special consideration shall be given to providing robustness to allow the removal of ice from the lifeboat without causing degradation of the integrity of the hull.

6.1.10.2 Enclosure is a recognized method for protecting objects vulnerable to icing from sea spray and may be applied as an alternative to providing the lifeboat with direct icing protection such as heat tracing. The enclosure shall be so designed that the lifeboat can be released without delay, regardless of metocean conditions and temperature.
6.2 Metallic structures

6.2.1 General

6.2.1.1 This subsection gives provisions for checking ultimate limit states for typical structural elements used in metallic components of free-fall lifeboats.

6.2.1.2 For steel structures, gross scantlings may be used to calculate the hull’s structural strength. A corrosion protection system in accordance with DNVGL-OS-C101 shall be installed and maintained.

6.2.1.3 Corrosion of aluminium structures leading to the loss of structural strength is not permitted, and shall be prevented by selecting appropriate corrosion-resistant alloys and corrosion protection. (This limits the choice of alloys for lifeboats to 5xxx and 6xxx series, as indicated in Sec.5.) Thus gross scantlings shall be used to calculate of structural strength.

6.2.1.4 For welded aluminium structures, the reduction of strength in the heat-affected zone (HAZ) shall be taken into account when calculating the structural strength.

6.2.1.5 When plastic or elastic-plastic analyses are used, checks shall be carried out to verify that plastic deformations will not accumulate in repeated launches in such a way that the structural reliability becomes less than that required in the ULS for single loads. The number of launches considered shall be in accordance with the intended use of the lifeboat, accounting for possible evacuations, training, tests, etc.

6.2.1.6 If plastic or elastic-plastic structural analyses are used to determine the sectional stress resultants, limitations on the width thickness ratios apply. The relevant width thickness ratios are found in the relevant codes used for capacity checks.

6.2.1.7 Cross sections of beams are divided into different types, depending on their ability to develop plastic hinges. A method for determining cross sectional types for steel structures is given in DNVGL-OS-C101 Appendix A. Corresponding information for aluminium structures is given in Eurocode 9, Part 1-1.

6.2.1.8 When plastic analysis and/or plastic capacity checks are used (cross section types I and II, according to DNVGL-OS-C101 Appendix A for steel, or classes 1 and 2 according to Eurocode 9 Part 1-1 for aluminium), the structural members shall be capable of forming plastic hinges with sufficient rotational capacity to enable the required redistribution of bending moments to develop. It shall also be checked that the load pattern will not change due to the deformations.

Guidance note:
The ductility in welds and HAZ of aluminium varies and cannot normally be assumed to provide sufficient rotational capacity to enable the required redistribution of bending moments to develop. It is therefore not recommended to use plastic capacity checks for welded aluminium structures unless the rotational capacity of the specific details is documented.

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6.2.2 Ductility

6.2.2.1 It is a fundamental requirement for metallic primary structures in free-fall lifeboats that all failure modes are sufficiently ductile such that the structural behaviour will be in accordance with the anticipated model used to determine of the responses. In general, no design procedures, regardless of analysis method, will capture the true structural behaviour. Ductile failure modes will allow the structure to redistribute forces in accordance with the presupposed static model. Ductile failure modes also ensure that the structure does not become unduly sensitive to unforeseen deviations of the loading conditions from those assumed in design. Brittle failure modes shall therefore be avoided.

6.2.2.2 The following sources of brittle structural behaviour shall be considered for a steel or aluminium structure:

— unstable fracture caused by a combination of the following factors: brittle material, low temperature in the material, a design resulting in high local stresses and the possibility of weld defects
— structural details where the ultimate resistance is reached with plastic deformations only in limited areas, making the global behaviour brittle
— shell buckling
Deflections causing the structure to strike occupants shall be treated as a brittle failure mode.

Guidance note:
For welded steel structures, the requirements in [6.2.7] prevent the localization of plasticity to the welds. The strength reduction in the heat-affected zone (HAZ) of welded aluminium structures tends to lead to the localization of plastic deformations in limited areas, thereby leading to unacceptable brittle structural behaviour.

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6.2.3 Yield check

6.2.3.1 Structural members, for which excessive yielding is a possible mode of failure, shall be investigated for yielding. The stresses to be considered are detailed in DNVGL-OS-C101.

6.2.3.2 Design stresses shall be established based on characteristic loads and/or characteristic stresses, specified in Sec.4, in conjunction with load factors, also specified in Sec.4. The design stresses shall not exceed the design resistance.

6.2.3.3 For yield checks of welded connections, see [6.2.8].

6.2.4 Buckling check

6.2.4.1 Elements of cross sections that do not fulfil the requirements for cross section type III (steel) or class 3 (aluminium) shall be checked for local buckling.

Steel cross section type III is defined in DNVGL-OS-C101 Appendix A. Aluminium cross section class 3 is defined in Eurocode 9 Part 1-1.

6.2.4.2 Buckling analysis shall be based on the characteristic buckling resistance of the structural member in the most unfavourable buckling mode.

6.2.4.3 The characteristic buckling strength shall be based on the 5th percentile of test results.

6.2.4.4 Initial imperfections and residual stresses in structural members shall be accounted for.

6.2.4.5 It shall be ensured that there is conformity between the initial imperfections in the buckling resistance formulas and the tolerances in the applied fabrication standard.

Guidance note:
If the buckling resistance of steel structures is calculated in accordance with DNV-RP-C201 for plated structures and with Classification Note 30.1 for bars and frames, the tolerance requirements given in DNVGL-OS-C401 should not be exceeded, unless specifically documented.

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6.2.5 Flat-plated structures and stiffened panels

6.2.5.1 The material factor $\gamma_M$ for plated structures is 1.15.

6.2.5.2 The buckling stability of plated steel structures may be checked according to DNV-RP-C201.

6.2.5.3 Stiffeners and girders may be designed according to provisions for beams in recognized standards such as Eurocode 3 (steel), Eurocode 9 (aluminium) or AISC LRFD Manual of Steel Construction.

6.2.5.4 Material factors when using Eurocode 3 and Eurocode 9 shall be taken as specified in [6.2.5.1].

6.2.5.5 Plates, stiffeners and girders may be designed according to NORSOK N-004 provided design loads and design load effects are established as specified in Sec.4.

6.2.5.6 Plating shall have sufficient thickness to ensure weldability and adequate resistance to local contact forces that may arise during fabrication, transport, storage and use.

6.2.5.7 Plating, stiffeners, beams and frames subjected to loading resulting from lateral pressure shall be designed accordingly. For steel structures, DNVGL-OS-C101 may be used for this purpose. For aluminium structures, Eurocode 9 Part 1-1 may be used. In either case, design loads and design load effects as specified in Sec.4 apply.
6.2.6 Shell structures

6.2.6.1 The buckling stability of cylindrical and unstiffened conical shell structures made of steel, including the interaction between shell buckling and column buckling, may be checked according to DNV-RP-C202.

6.2.6.2 If DNV-RP-C202 is applied, the material factor for shells shall be in accordance with Table 6-1.

<table>
<thead>
<tr>
<th>Type of structure</th>
<th>$\lambda \leq 0.5$</th>
<th>$0.5 &lt; \lambda &lt; 1.0$</th>
<th>$\lambda \geq 1.0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girders, beams and stiffeners on shells</td>
<td>1.15</td>
<td>1.15</td>
<td>1.15</td>
</tr>
<tr>
<td>Shells of single curvature (cylindrical shells)</td>
<td>1.15</td>
<td>0.85 + 0.60 $\lambda$</td>
<td>1.45</td>
</tr>
</tbody>
</table>

Note that the slenderness is based on the buckling mode under consideration.

$\lambda$ = reduced slenderness parameter

$\frac{f_y}{\sigma_e}$ = specified minimum yield stress

$\sigma_e$ = elastic buckling stress for the buckling mode under consideration.

6.2.6.3 The buckling stability of stiffened and unstiffened axisymmetric shell structures (cylindrical, conical or spherical) made of aluminium may be checked according to Eurocode 9, Part 1-5.

6.2.6.4 If Eurocode 9, Part 1-5 is applied, the material factor $\gamma_{M1}$ shall be taken as 1.15.

6.2.7 Special provisions for web frames, girders and girder systems

6.2.7.1 Special provisions for web frames, girders and girder systems are given in DNVGL-OS-C101.

6.2.8 Welded connections

6.2.8.1 Welded steel connections shall be designed according to requirements given in DNVGL-OS-C101. Welded aluminium connections shall be designed according to requirements given in DNV Rules for High Speed Light Craft, Pt.3 Ch.3 Sec.8. In either case, design loads and design load effects as specified in Sec.4 apply.

6.2.8.2 In the design of welded joints in aluminium structures adjacent to the weld, consideration shall be given to the strengths of both the welds and the HAZ. For the following alloys, a reduction of yield strength in the HAZ shall be taken into account:

— heat-treatable alloys (6xxx series) in temper T4 and above
— nonheat-treatable alloys (5xxx series) in any work-hardened condition.

The severity and size of the HAZ depend on the welding method. Guidance may be obtained from Eurocode 9 Part 1-1.

6.2.8.3 In aluminium structures, the strength of the weld metal is usually lower than the strength of the base metal except for the strength in the HAZ. Characteristic yield strengths for weld metal can be found in Eurocode 9 Part 1-1, Section 8.6. Yield strengths are also given in DNV Rules for Classification of High Speed, Light Craft and Naval Surface Craft, Pt.2 Ch.3 Sec.2.
6.3 Composite structures: single-skin and sandwich constructions

6.3.1 Application

6.3.1.1 The requirements in this subsection apply to structures of FRP single skin construction and sandwich construction. The plastics used in such applications shall be of a type that has documented good durability performance in the maritime environment.

6.3.1.2 A single skin construction is considered to be a structure consisting of an FRP shell laminate supported and stiffened locally by a system of closely spaced FRP stiffeners.

6.3.1.3 A sandwich construction is considered to be a structural element consisting of three components: an FRP skin laminate on each side of a low density core. The properties and proportions of the component materials shall be such that, when a sandwich panel is exposed to a lateral load, the bending moments are carried mainly by the skins and the shear forces mainly by the core.

6.3.1.4 Sec.5 contains a set of requirements to be followed for the manufacturing and quality assurance of FRP structures.

6.3.2 Design principles

6.3.2.1 It is a fundamental requirement for FRP primary structures in free-fall lifeboats that the structure has a good damage tolerance and resistance to the propagation of fractures in the governing load cases. The fracture resistance in composite structures is an inherent property of well-designed fibrous composite laminates and does not require the material to exhibit ductile behaviour. Hence, while metallic structures need to fulfil ductility requirements, composite structures need to meet requirements that ensure a proper arrangement of fibre reinforcement and load-carrying members. These requirements are given in this subsection.

6.3.2.2 The lifeboat shall be designed such that the loads are carried mainly by the fibres. The fibres shall therefore be aligned close to the direction or directions of the largest principal stress in the governing load conditions.

6.3.2.3 Failure governed by the polymeric matrix shall be inhibited by alignment of the fibres according to [6.3.2.2] and by use of a ply stacking sequence without any clustering of plies with the same fibre direction. Note that matrix cracking, caused by loading carried by fibres aligned in appropriate directions and often referred to as first ply failure (FPF), is not considered a structural failure and thus need not be accounted for in the design.

6.3.2.4 In order to maintain the specified level of safety at least for the specified service life of the lifeboat considering the intended use of the lifeboat and the anticipated environmental exposure, and to provide the robustness needed to sustain the impact and abrasive loading expected when operated as intended, the following requirements for minimum scantlings shall be complied with unless equivalent robustness is documented for an alternative arrangement.

The reinforcement of laminates is to contain at least 25% continuous fibres by volume. The mechanical properties of the core material of structural sandwich panels are to comply with the minimum requirements given in Table 6-2.

<table>
<thead>
<tr>
<th>Structural member</th>
<th>Core properties (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shear strength</td>
</tr>
<tr>
<td>Hull structure</td>
<td>0.8</td>
</tr>
<tr>
<td>Internal structure</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The amount of reinforcement (g/m²) in skin laminates in structural sandwich panels shall normally not be less than that given in Table 6-3.
6.3.2.5 Suitable local reinforcement and higher-strength core materials shall be applied in all through-bolt connections in girders that support the engine and gear and in other places where large through-thickness compression loads occur.

6.3.2.6 Joints within or connecting primary structural elements shall be designed so that the joint itself does not govern the capacity of the structural elements in their primary load-bearing functions. This includes, but is not limited to, the following two examples:

— For frames and stiffeners, whose primary load-bearing function is to transmit bending moments and shear forces as a beam to the support points, a joint between the hull plating acting as the flange and the web shall be designed with a shear capacity that is not smaller than that of the web itself.

— A joint connecting the superstructure to the hull and on which the hull girder depends for its bending and shear capacity shall be designed with a shear capacity that is not smaller than that of the adjoining laminates of the hull and superstructure.

6.3.2.7 The connection of the skin laminates shall be arranged in such a manner that laminate peeling is effectively arrested.

6.3.2.8 Out-of-plane joints shall be so designed as to primarily be loaded in compression and shear. The overlap laminates should have sufficient width and thickness to transmit the shear forces from the respective adjoining panel to the supporting panel. If the local compressive stresses in the core exceed the compression capacity of the core material, strong core inserts should be used. Local bending at the joint should be considered if the adjoining panel forms a tank boundary or would otherwise support a transverse load during the operation of the lifeboat. The performance of the joints should be documented with component tests unless solutions are used that have a documented good service track record.

6.3.2.9 To limit peel and defect sensitivity and provide adequate load-bearing capacity, the overlap length should be at least

$$l_{\text{min}} = 1.5 \cdot t \cdot \frac{\sigma_u}{\tau_p}$$

where $l_{\text{min}}$ is the minimum overlap, $t$ is the thickness of the thinnest laminate adherend, $\sigma_u$ is the ultimate capacity of that laminate in the direction of the loading to be transmitted by the bonded joint and $\tau_p$ is the ultimate plastic shear capacity of the adhesive measured according to a recognized standard such as ASTM D1002, D3163 or D3528.

**Guidance note:**
This condition is necessary but not sufficient to provide reliable bonded joints; note also the requirement for the load-bearing capacity of the joint in [6.3.7].

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6.3.2.10 The design of the vessel is to be based on mechanical properties that are representative for the raw materials, production method(s), workshop conditions, lay-up sequence, etc., that are used and for the material quality that is expected over time from continuous production by the contracted builder as set out in [5.6.3.3] to [5.6.3.8].

6.3.2.11 This shall be confirmed by production testing according to [5.6.3.9]. The purpose of production testing is to verify that a consistent level of quality is maintained throughout production, i.e. that gross errors have not occurred in production. The production testing shall be carried out according to a production test plan, which shall be provided in the design phase. The test plan shall be designed to efficiently detect gross errors that can potentially occur in production considering the manufacturing methods and assembly procedures adopted and the raw materials used.

6.3.2.12 The production test plan shall as a minimum address the following items:

- mechanical strength of sandwich skin laminates, single skin laminates, flanges (caps) of stringers and girders
- bond strength between the core and skin laminates in sandwich panels
- mechanical strength of major attachments and joints
- acceptance criteria.

6.3.2.13 The test methods specified in Sec. 5 shall be used. Through-thickness tests shall be carried out according to ASTM C297. For details considered critical with respect to compressive loads consideration shall be given to the need to perform compression tests instead of or in addition to the tensile tests.

6.3.2.14 The test samples shall be taken from cut-outs in the hull and main deck. All such cut-outs shall be identified by marking and be stored until used for testing purposes or until completion of the vessel. If adequate cut-outs cannot be obtained, spare laminate for testing shall be made in parallel with the main production work.

6.3.3 Structural calculations

6.3.3.1 The governing load effects shall be established from structural calculations performed according to established engineering methods for composite materials. The need to account for out-of-plane deformations in sandwich and single skin structures shall be considered. Simplified hand calculations can only be used provided the accuracy of the method has been documented and all the underlying assumptions have been complied with.

Guidance note:
FEA will normally be required for lifeboats.

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6.3.3.2 The effective panel flange area is defined as the cross-sectional area of the panel within the effective flange width. For sandwich panels, only the skin laminate at which the beam is fitted shall be considered as effective flange unless the contribution from the opposite side is documented for the case in question. The effective flange for a uniformly loaded beam, considering only the contribution from one face, is found from Figure 6-2.
The length to be used with the diagram in Figure 6-2 is the length between the moment inflection points, i.e. between zero bending moments. The breadth $b$ is to be taken as the c/c distance between the stiffeners or girders. For a beam with fixed ends, the length between inflection points is $0.58 I$. For beams with fixed ends, the effective flange outside the inflexion points (i.e. at the ends) is to be taken as 0.67 times the effective flange calculated above.

**Guidance note:**
For top hat stiffeners with UD tabbing underneath where the tabbing width is less than twice the width of the top hat base, the full width of the tabbing may be used.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Laminates with $E/G$ ratios above 3.3 are to be corrected for increased shear lag effect in the flange. The effective flange is then to be taken as:

$$b_{eff} = \frac{1}{1 + 3.3 \cdot \frac{E}{G} \left( \frac{b}{I} \right)}$$

$b_{eff}$ = effective breadth of flange  
$b$ = panel breadth between beams  
$E$ = $E$ modulus of flange laminate  
$G$ = shear modulus of flange laminate  
$I$ = length of beam

6.3.3.3 The total stresses combining the contributions from the local response of plates and stiffeners, response of the framing system and the global response of the hull shall be used in the capacity checks of fibre-reinforced composite materials. If stresses at the various levels are calculated separately, the individual stress components shall be combined to produce an estimate of the total stress.

**Guidance note:**
As a conservative approach, the individual stresses can simply be added together. Information about the phasing between the individual stresses may be used to document a lower combined stress.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

6.3.3.4 Further detailed guidance on finite element analysis can be found in App.8.
6.3.4 Laminate rupture

6.3.4.1 Fibre failure is defined here as the failure of a ply due to a fracture of the reinforcing fibres. Failure shall be checked for at the ply level, not the laminate level. The maximum strain criterion can be used to check fibre failures.

\[ \varepsilon_{n k} < \frac{\varepsilon_{n k}^{fiber}}{\gamma_m} \]

Other design criteria may be used if it can be shown that they are equal to or conservative compared to the maximum strain criterion given here.

6.3.4.2 For laminates with a lay-up with fibre orientation seen through the entire thickness that implies fibre directions more than 45° apart, matrix cracking or deformation due to in-plane ply shear stresses (not considered a failure in itself) may trigger progressive damage accumulation that could lead to rupture of the laminate. To prevent this, it should be documented that matrix cracks or deformations can be tolerated by the laminate under the relevant loading conditions by use of a suitable laminate failure criterion. The maximum fibre strain criterion is not suitable for documenting this. Failure of such laminates may be assessed using the Tsai-Wu laminate failure criterion:

\[ R^2 \left( F_{11}' \sigma_{11}^2 + F_{22}' \sigma_{22}^2 + F_{12}' \sigma_{12}^2 + 2 F_{12}' \sigma_{11} \sigma_{22} + 2 H_{12}' \sigma_{12} \sigma_{11} + 2 H_{12}' \sigma_{12} \sigma_{11} \right) + R \left( F_{11}' \sigma_{11} + F_{22}' \sigma_{22} \right) < 1 \]

with

\[ R = \gamma_n, \quad F_{11} = \frac{1}{\sigma_n \sigma_m}, \quad F_{22} = \frac{1}{\sigma_n \sigma_m}, \quad F_{12} = \frac{1}{\sigma_{12} \sigma_{12}}, \quad F_1 = \frac{1}{\sigma_n} - \frac{1}{\sigma_m}, \quad F_2 = \frac{1}{\sigma_n} - \frac{1}{\sigma_m}, \quad H_{12} = H_{12}' \sqrt{F_{11} F_{22}} \]

where

- \( n \) the coordinate system is the ply coordinate system; \( n \) refers to the directions 1, 2 and 12.
- \( \sigma_n \) characteristic value of the local load effect of the structure (stress) in the direction \( n \)
- \( \sigma_{nt} \) characteristic tensile strength in the direction \( n \)
- \( \sigma_{nc} \) characteristic compressive strength in the direction \( n \)
- \( \sigma_{nk} \) characteristic shear strength in the direction \( nk \)
- \( \gamma_m \) partial resistance factor (material factor).

The interaction parameter \( H_{12}'^* \) can be taken by default as a value between -0.5 and 0 or it can be determined experimentally for the actual material.

6.3.4.3 The strength properties shall be taken as described below. Characteristic strengths as described in [5.6.3] shall always be used.

- \( \sigma_{tt} \) tensile ply strength in the fibre direction, as defined in Sec.5.
- \( \sigma_{tc} \) compressive ply strength in the fibre direction, as defined in Sec.5.
- \( \sigma_{tr} = \frac{E_t}{E_t} \sigma_{tt} \) modified in-plane tensile ply strength transverse to the fibres.
- \( \sigma_{tc} = \frac{E_t}{E_t} \sigma_{tt} \) modified in-plane compressive ply strength transverse to the fibres.
6.3.5 Core shear fracture

6.3.5.1 A core shear fracture shall be assumed to occur if the shear stress predicted in the core in response to the design load exceeds the characteristic shear strength of the core material established according to Sec.5

\[ \tau < \frac{\tau_c}{\gamma_m} \]

where \( \tau \) is the maximum shear stress occurring in the core and \( \tau_c \) is the characteristic shear strength of the core according to Sec.5.

6.3.6 Face wrinkling

6.3.6.1 The critical local buckling stress for skin laminates exposed to compression is given by

\[ \sigma < \frac{0.5 \sqrt{E_c G_c E_f}}{\gamma_m} \]

where \( E \) denotes Young's modulus, \( G \) the shear modulus, index \( c \) refers to the core and \( f \) to the face sheets (skins). The modulus for the face laminate \( E_f \) used in this expression shall be taken as the flexural bending modulus measured directly from a bend test of a laminate with the actual lay-up or estimated from ply properties and lay-up using laminate theory.

6.3.7 Fracture of bonded joints

6.3.7.1 The capacity of joint designs for which a successful service track record is lacking should be established by component tests for the critical modes of loading. The tested characteristic capacity in each relevant mode of loading shall be verified as exceeding the maximum occurring load effect by a sufficient margin

\[ S_i < \frac{R_i}{\gamma_m} \]

where \( S_i \) is the load effect component considered (e.g. bending, shear, tension, compression), \( R_i \) is the corresponding characteristic capacity from tests calculated according to the method given in [5.6.3.3] and \( \gamma_m \) is the material factor. This safety factor may need to be increased for joint designs where the resistance to combined loads can be expected to be less than the resistance to the load components considered individually.

6.3.7.2 A successful service track record for a specific joint can be considered to apply to bonded joints with the same overall geometry, the same materials and the same bonding procedures and with adherend laminates whose strengths are equal to or less than the strengths of the adherend laminates of the joint for which the experience was recorded.

6.3.8 Bolted connections

6.3.8.1 This paragraph provides general requirements for the strength of the following types of bolted connections:

- bolted connections for the transfer of in-plane loads (shear connections)
- bolted connections for the transfer of out-of-plane loads
- bolt inserts and similar attachments (not participating in the structural strength of the hull and superstructure).

The definition of in-plane and out-of-plane loads refers to the load components on each individual bolt.
The thickness of the laminates may have to be increased to accommodate the localized loads from a bolted connection.

Definitions are given in Figure 6-3, which refers to the following symbols:

- \( d \) = bolt diameter
- \( e_1 \) = edge distance transverse to the direction of the load
- \( e_2 \) = edge distance in the direction of the load
- \( p_1 \) = bolt pitch transverse to the direction of the load
- \( p_2 \) = bolt pitch in the direction of the load

![Figure 6-3 Direction of load on bolt hole](image)

**6.3.8.2** Bolted shear connections are only acceptable in laminates with reinforcement placed in at least two directions. The smallest angle between at least two reinforcement directions shall not be smaller than 35° (does not apply to pure CSM laminates). CSM plies in a combined laminate shall not be included when calculating the capacity of the connection.

**6.3.8.3** The surface of the part of the bolt that is inside the laminate shall be smooth. No threads are allowed in this area.

**6.3.8.4** A washer with an outer diameter not less than 3 \( d \) shall be used under the bolt head and nut. The washer shall have adequate stiffness such that the bolt pretension is distributed under the area of the washer. Only flat-face bolts shall be used. Countersunk and tapered bolt heads are not acceptable due to the risk of the laminate being split by the wedge effect of the bolt head.

**6.3.8.5** The bolt shall be tightened with such a force that single skin laminates connected by bolting are subjected to a nominal compressive stress under the washers that exceeds 15 MPa but does not exceed 30 MPa. The nominal stress is calculated as the compressive load on the bolt divided by the surface area of the washer. Due to the creep (and thus stress relaxation) that can be expected in the laminate, bolts should be re-torqued after a period of time not shorter than 2 weeks.

**6.3.8.6** The pitch transverse to the direction of the load shall satisfy \( p_1 \geq 5 \, d \).
The pitch in the direction of the load shall satisfy \( p_2 \geq 4 \, d \).
The edge distance transverse to the direction of the load shall satisfy \( e_1 \geq 3 \, d \).
The edge distance in the direction of the load shall satisfy the following requirement: \( e_2 \geq 4 \, d \).

**6.3.8.7** The characteristic nominal bearing stress shall satisfy the following requirement:

\[
\sigma_{\text{bear}} = \frac{R_{\text{bear}}}{\gamma}
\]

\( \sigma_{\text{bear}} \) = characteristic shear load divided by \( d \cdot t \)
The default values of the bearing stress capacity \( R_{\text{bear}} \) given in Table 6-5 can be used. Higher bearing stress capacity can be used based on representative test results.

For hybrid laminates, \( R_{\text{bear}} \) can be found by linear interpolation based on the volume fraction of the respective types of fibre.

Guidance note:
The requirements are such that it is highly probable that the failure mode will be that the bearing stress exceeds the capacity around the edge of the hole.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

### Table 6-5 Default values of the bearing stress capacity

<table>
<thead>
<tr>
<th>Type of reinforcement</th>
<th>Nominal bearing stress strength, ( R_{\text{bear}} ) (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass, woven roving</td>
<td>200 ( (V_f/0.33) )</td>
</tr>
<tr>
<td>Glass, multiaxial laminates</td>
<td>250 ( (V_f/0.33) )</td>
</tr>
<tr>
<td>Glass, CSM</td>
<td>75 ( (V_f/0.33) )</td>
</tr>
<tr>
<td>Carbon, woven roving</td>
<td>275 ( (V_f/0.50) )</td>
</tr>
<tr>
<td>Carbon, multiaxial laminates</td>
<td>325 ( (V_f/0.50) )</td>
</tr>
<tr>
<td>Aramid, woven roving</td>
<td>According to test</td>
</tr>
<tr>
<td>Aramid, multiaxial laminates</td>
<td>According to test</td>
</tr>
</tbody>
</table>

\( V_f = \) volume fraction of reinforcement in laminates excluding CSM layers in laminates with layers of continuous fibres.

6.3.8.8 A connection for out-of-plane loads shall be bolted through the panel, and in sandwich panels through both skins.

6.3.8.9 Washers or plates shall be provided on both sides of the panel to distribute the load from bolt heads and nuts. These washers or plates may be fabricated from metallic materials or fibre-reinforced thermosets.

6.3.8.10 Their bending stiffness shall be large enough to ensure a distribution of the load from each bolt over a sufficiently large area to prevent compressive overloading of the panel in between the washers or plates. The combined compressive stress under the washer or plates, resulting from the pretension of the bolt and the out-of-plane loading, shall not anywhere exceed 30% of the compressive strength of the skin and the core, respectively.

6.3.8.11 The global effect of the out-of-plane load on the panel (in-plane bending moments and through thickness shear) shall be calculated according to recognized methods for calculating load effects in panels subjected to concentrated loads. The stress levels in laminates, skins and the core shall satisfy the limit states of this section.

6.3.8.12 Other arrangements may be accepted based on component test results. Such testing shall be carried out on connections with a representative design on representative panels subjected to representative loads, including all in-plane and out-of-plane components. The tested characteristic capacity in each relevant mode of loading shall be verified as exceeding the maximum occurring load effect by a sufficient margin

\[
S_i < \frac{R_i}{\gamma_m}
\]

where \( S_i \) is the load effect component considered (e.g. bending, shear, tension, compression), \( R_i \) is the corresponding characteristic capacity calculated in tests according to the method given in [5.6.3.3], and \( \gamma_m \) is the material factor. This safety factor may need to be increased for joint designs where the resistance to combined loads can be expected to be less than the resistance to the load components considered individually.

6.3.8.13 Inserts and attachments may be used for transferring in-plane and out-of-plane loads for connections not participating in the structural strength of the hull and superstructure.
6.3.8.14 Where adequate, the design methods described above may be used.

6.3.9 Long-term performance

6.3.9.1 It is not required to explicitly assess low-cycle fatigue due to repeated launches of lifeboats made of composite materials.

6.3.9.2 Degradation or failure due to creep or sustained stresses shall be assessed for details exposed to long-term static loads. This is of particular relevance for the release mechanism and its attachment to the lifeboat and any details that are subject to considerable static loads from the supports during stowage.

6.3.10 Material factors

6.3.10.1 The material factor $\gamma_m$ is to be taken as the product of a short term material factor $\gamma_{ms}$ and a long-term material factor $\gamma_{ml}$.

6.3.10.2 The short-term material factor $\gamma_{ms}$ is intended to account for the variability in the capacity from instance to instance due to the variability in raw materials, manufacturing conditions and workmanship, as well as for the uncertainty in the short-term capacity after exposure to the service environment. For material strengths with a coefficient of variation less than 10%, the short-term material factor $\gamma_{ms}$ shall be taken according to Table 6-6.

6.3.10.3 The long-term material factor $\gamma_{ml}$ is intended to account for the uncertainty in the long-term capacity caused by the characteristic capacity being estimated from short-term tests. If raw materials and manufacturing procedures are used that have a proven track record from service in the maritime environment, the long-term material factor $\gamma_{ml}$ can be taken according to Table 6-6. Otherwise, the long-term performance must be assessed based on separate documentation of the long term performance for the particular material and design. When there are no long-term static load effects, such as for the short-term loads that occur only during a lifeboat launch, the long-term material factor $\gamma_{ml}$ shall be taken as 1.0.

Table 6-6 Short-term and long-term material factors $\gamma_{ms}$ and $\gamma_{ml}$ for typical materials and details of lifeboats

<table>
<thead>
<tr>
<th>Part of structure</th>
<th>$\gamma_{ms}$</th>
<th>$\gamma_{ml}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre-dominated laminates *)</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Stiffness-dominated failure mechanisms (e.g. buckling, wrinkling)</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Matrix-dominated laminates $\gamma_{ml}$, $\gamma_{ms}$ $\gamma_{ml}$, determined experimentally for specific material</td>
<td>1.75</td>
<td>2.7 **</td>
</tr>
<tr>
<td>Ductile core materials</td>
<td>1.35</td>
<td>2.7</td>
</tr>
<tr>
<td>Other core materials</td>
<td>1.5</td>
<td>2.7</td>
</tr>
<tr>
<td>Overlap joints predominately transferring loading by shear across the bondline</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>(e.g. simple overlap joints loaded in tension or in-plane shear, T-joints where adjoining panel is loaded in in-plane shear)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complex joints also transferring loading by tension across the bondline (peel, cleavage)</td>
<td>1.75</td>
<td>2.0</td>
</tr>
<tr>
<td>(e.g. T-joints where adjoining panel is loaded in bending or tension, see [6.3.2.8])</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Fibre-dominated laminates are laminates that have continuous fibres with fibre orientation seen through the entire thickness that implies fibre directions not more than 45° apart and laminates in a predominantly uniaxial stress state (i.e. flange laminates) with fibres oriented in the principal stress direction. Matrix-dominated laminates are all other laminates.

** It is generally recommended to use fibre-dominated laminates in areas exposed to long-term loads.
SECTION 7 OPERATIONAL REQUIREMENTS

7.1 Introduction

7.1.1 General

7.1.1.1 This section provides operational requirements for free-fall lifeboats during various phases of their operation, including mustering, boarding, release, free fall, resurfacing and sailing to a safe area.

7.1.1.2 Two of the main purposes of the operational requirements are to ensure sufficient headway away from the host facility once the lifeboat has been launched and to ensure safe operation in the subsequent sailing phase until retrieval of the occupants takes place.

7.2 Mustering and boarding

7.2.1 Muster area

7.2.1.1 The muster area shall meet the requirements set forth in NORSOK S-001.

7.2.2 Boarding

7.2.2.1 The access to the lifeboat from the muster area shall be efficient. Once the occupants are inside the lifeboat, the access to each individual seat shall also be efficient. Without any injured personnel to be brought on board the lifeboat, the maximum time for boarding, measured from when boarding begins until the lifeboat is ready for launching, shall be 3 minutes.

Guidance note:
Fulfilment of the requirement of 3 minutes maximum time for boarding will be facilitated by ensuring easy access to the individual seats and by ensuring user-friendly harness arrangements in each seat.

The fulfilment of boarding time requirements can be verified by embarkation trials with time registrations.

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7.2.2.2 Provisions shall be made for safe and ergonomic entry to the lifeboat in all conditions, including if the host facility is damaged. For damaged host floaters with trim and list, it shall be demonstrated that it is possible to enter the lifeboat and all the lifeboat seats safely. Trim and list depend on the stability of the host facility and the possible loss of buoyancy in one or more supporting buoyant compartments. The trim and list for the damaged host facility shall be set to ±17° unless other host-facility-specific values are known.

7.2.2.3 The crew shall see to it that the occupants disperse themselves as symmetrically as possible around the middle of the boat, and as uniformly as possible between the bow and the stern, such that the loading of the boat becomes approximately symmetrical.

7.3 Launch

7.3.1 Release function

7.3.1.1 The lifeboat shall be equipped with two independent activation systems for the release mechanisms. The release systems shall be designed such that the lifeboat can only be released from inside the lifeboat. Each activation system shall be so designed that the release of the lifeboat requires simultaneous operation by two crew members.

Guidance note:
Only one activation system is normally used to release the lifeboat. The requirement of two independent activation systems represents a requirement of redundancy. The requirement of two crew members to simultaneously operate the activation system is given for safety reasons.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

7.3.1.2 To allow for installation tests despite the fact that the lifeboat can only be released from inside the lifeboat, a system for hanging off the lifeboat in the lifeboat station shall be implemented.
Guidance note:
A hang-off system is a fall arrest device used to release the lifeboat without dropping it into the sea. For the purpose of installation tests, in order to avoid exposing persons to risk, a purpose-built system for remote operation of the activation systems may be utilized, allowing the lifeboat to be released from the outside.

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7.3.2 Rudder

7.3.2.1 The rudder shall be set in the middle position prior to the launch in order to prevent the rudder from being knocked askew during the launch and to prevent an off-middle rudder position from causing the lifeboat to deviate from its straight ahead course during its submerged phase. The lifeboat shall be furnished with a rudder indicator.

Guidance note:
To ease the duties of the pilot, the requirement to set the rudder in the middle position can be met by implementing a rudder system which returns to neutral when the steering wheel is released, i.e. a follow-up system with a return to neutral.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

7.3.3 Start of engine

7.3.3.1 The engine shall be started prior to the release of the lifeboat from the lifeboat station, provided the transmission is not engaged. The transmission shall be engaged as soon as possible after water entry.

7.3.3.2 The requirement to start the engine prior to the release of the lifeboat may be waived in an emergency situation where gas is present and the lifeboat is to be launched into a following wind.

Guidance note:
When gas is present, the gas may blow towards the lifeboat station and be ignited by sparks from the lifeboat’s running engine if the lifeboat is to be launched into a following wind.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

7.3.3.3 The requirement that the transmission shall not be engaged until after water entry may be waived when it can be documented that the propeller will not be damaged if the transmission is engaged prior to and during water entry.

7.4 Water entry and resurfacing

7.4.1 Rudder control

7.4.1.1 The pilot shall take control of the rudder as soon as possible after water entry.

Guidance note:
Use of an autopilot is recommended, provided a robust technical solution is available. Use of an autopilot necessitates a lifeboat with fully automatic control of the rudder after the launch.

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7.4.2 Position and headway

7.4.2.1 The lifeboat shall possess and be able to maintain directional stability after water entry and resurfacing and shall not lose its course in this phase. With the thrust engaged and the rudder fixed in the middle position, the lifeboat shall be able to sail straight ahead.

Guidance note:
To possess and maintain directional stability, the lifeboat must achieve and maintain a positive mean headway relative to the host facility from water entry onwards. The time at which the engine and transmission are engaged after water entry becomes very important in this context. Mean headway refers to the speed averaged over a time span of several wave periods.

To ensure adequate headway in the phase immediately after water entry and resurfacing, the propeller must be engaged immediately after water entry and, if possible, automatically without action from the pilot, and a sufficient propulsion force must be provided immediately by the propeller. The lifeboat must have a documented directional stability with the rudder fixed in the middle position, and the pilot must not have to carry out other activities before taking control of the rudder.

An additional propulsion system in front will improve the directional stability of the lifeboat compared to a propulsion system in the aft only.
Course refers to the direction averaged over a time span of several wave periods.

7.4.2.2 It shall be possible to keep the lifeboat on a stable diagonal course relative to wind and waves, i.e. the thrust moment induced from the hydrodynamic lift force on the rudder must be large enough to counteract the wave-, current- and wind-induced moments.

Guidance note:
In order for a lifeboat to move forward on a stable course in wind and waves, there must be equilibrium between the moments induced by the propulsive forces, hydrodynamic forces on hull and rudder and wind forces on the lifeboat hull and canopy. The rudder must be large enough and be designed so that it can provide sufficient lift forces in a specific position to counteract moments induced by the wave and wind forces at all operating speeds.

7.4.2.3 The lifeboat shall not collide with the host facility. This no-collision requirement can be fulfilled by keeping the probability of collision in a 3-hour stationary sea state, whose significant wave height has a return period of 100 years, less than or equal to $10^{-2}$.

Guidance note:
At any point in time, the horizontal distance between the lifeboat and host facility is defined as the shortest distance between the two. In a preliminary design phase for a lifeboat on a bottom-fixed host facility, the no-collision requirement can be considered fulfilled when the lifeboat follows Motion Pattern 1 and the horizontal distance between the lifeboat and host facility, at the time of resurfacing and in a situation with calm water and no wind, is demonstrated to be no less than 40 m.
The time of resurfacing shall then be taken as the point in time when the trajectory of the COG of the lifeboat with its full load of occupants passes up through the SWL after water entry.
The substitute requirement of at least 40 m distance in a situation with calm water and no wind has been set such that requirements for the safety against collision are met during a launch at an arbitrary point in time as well as during a launch in a 100-year sea state.
The requirement of at least 40 m distance accounts for the effects of:
- wind action during the free fall
- movement towards the host facility caused by wave action
- wind-induced current and wind-induced drift
- the time it takes to engage the transmission and gain speed after resurfacing.
To the extent that the distance between the lifeboat and host facility at the time of resurfacing, in a situation with calm water and no wind, varies from one launch to another, it suffices to apply the expected value of the distance in order to document that the requirement is fulfilled.
The substitute requirement of at least 40 m distance cannot be used to demonstrate fulfilment of the no-collision requirement in the final design.
The substitute requirement of at least 40 m distance cannot be used to demonstrate fulfilment of the no-collision requirement for lifeboats to be launched from floating host facilities.
The no-collision requirement can be met in ways other than by fulfilling the requirement for distance at the time of resurfacing, for example by adequate simulations, model tests and CFD analysis, as long as it is documented that the safety against collision meets the requirements set forth in [2.2.5].

7.4.3 Stability

7.4.3.1 Lifeboats that become fully submerged after water entry shall be stable and have a positive righting moment for the following two load cases when the lifeboat is in the fully submerged condition:
- fully loaded lifeboat (lifeboat with the weight of the full complement of occupants)
- empty lifeboat (lifeboat with the weight of three persons).
For either load case, the submerged stability can be documented by calculating the immersed transversal position of the centre of buoyancy and making sure it is located above the transversal position of the centre of gravity.

7.5 Sailing phase

7.5.1 General

7.5.1.1 Two positions for manoeuvring the lifeboat shall be provided with redundancy of rudder control, engine control and main instruments. The two positions shall be used by the pilot and another crew
member. The two positions for manoeuvring the lifeboat shall be so arranged that the occupants in these two manoeuvring positions need not change seats after water entry and resurfacing.

Guidance note:
The pilot and other crew member in the two manoeuvring positions shall independently be able to control the lifeboat from their respective seat positions. This will ensure the safer operation of the lifeboat in the case of pilot injuries during water entry and resurfacing.

The fact that the pilot can remain in his or her seat after the free fall and manoeuvre the lifeboat from the same seat as the seat he or she is in during the free fall will save valuable time. Time will then not be wasted on unbuckling the harnesses and moving to another seat to take control of the lifeboat after water entry and resurfacing. The position and orientation of the seat need not be the same during the free fall and sailing phase, and a mechanical device can be used to bring the seat from the position and orientation during the free fall to the manoeuvring position needed in the sailing phase.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

7.5.1.2 In the sailing phase, the pilot shall in so far as possible only be occupied with manoeuvring the lifeboat. Other crew members should therefore operate the VHF radio and other equipment which needs attention or handling during the sailing phase. The operator of the VHF radio shall use a headset. The headset shall be connected to the radio prior to the lifeboat launch, so that it is ready for use from the beginning of the sailing phase.

7.5.1.3 Two conditions for harsh weather are considered:
— a test sea state defined in terms of a significant wave height $H_S$ of at least 4 m
— a 100-year sea state defined in terms of the 100-year value of $H_S$.

7.5.1.4 The lifeboat performance in the sailing phase including headway, manoeuvring and motion response (seakeeping), shall be documented by full-scale tests or adequate numerical simulations, e.g. CFD analysis. Numerical simulations shall be validated against model tests.

7.5.2 Buoyancy and stability

7.5.2.1 The lifeboat shall have inherent buoyancy or shall be fitted with inherently buoyant material which shall not be adversely affected by seawater, oil or oil products, sufficient to keep the lifeboat afloat with all its equipment on board when the lifeboat is flooded and the hatch is open to the sea. When the lifeboat is in the stable flooded condition, the water level inside the lifeboat, measured along the seat back, shall not be more than 500 mm above the seat pan at any occupant seating position. Additional inherently buoyant material, equal to 280 N of buoyant force per person, shall be provided for the number of persons that the lifeboat is designed to accommodate. Buoyant material provided according to this item shall not be installed external to the hull of the lifeboat.

7.5.2.2 The lifeboat shall be stable and have a positive metacentric height when it is loaded with 50% of the number of occupants that it is designed to accommodate, placed in their normal positions to one side of the centreline of the lifeboat. In this loading condition, the heel of the lifeboat shall not exceed an angle of 20°, and the lifeboat shall have a freeboard, measured from the waterline to the lowest opening through which the lifeboat may become flooded, equal to at least 1.5% of the length of the lifeboat and not less than 100 mm. The freeboard shall be documented by freeboard tests.

7.5.2.3 The lifeboat shall have self-righting ability in the surface condition after resurfacing. The self-righting ability can be documented by tests.

Guidance note:
The stability and self-righting ability depend on the complement of occupants strapped into their seats. If the weight distribution in the lifeboat changes, these characteristics may suffer or even disappear.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

7.5.3 Thrust and rudder

7.5.3.1 In calm water, the thrust and rudder capacity shall be sufficient to maintain a mean direction and a mean headway speed equal to or greater than 3 m/s. When the lifeboat is towing an identical lifeboat in calm water, the thrust and rudder capacity shall be sufficient to maintain a mean headway speed equal to or greater than 1 m/s. Both requirements shall be fulfilled based on the assumption that the lifeboat is fully loaded with the weight of its full complement of occupants.
Guidance note: Adequate shaping of the stern can facilitate the fulfilment of the headway requirements as can increasing the size of the propeller and increasing the engine power.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

7.5.3.2 In the test sea state defined in [7.5.1.3], the thrust and rudder capacity shall be sufficient to maintain a mean direction and a mean headway speed equal to or greater than 2.5 m/s. This requirement shall be fulfilled if the lifeboat is empty, i.e. the lifeboat is loaded with the weight of three persons, e.g. a crew of three including the pilot. The requirement shall be fulfilled in all directions.

Guidance note: In harsh weather conditions, ocean surface waves are much longer than the dimensions of the lifeboat, which means that the lifeboat will more or less follow the wave surface and move up and down with an amplitude similar to the amplitude of the wave. Without forward thrust, the lifeboat will also move back and forth with this amplitude since the water particles in the wave move in approximately circular orbits. A mean drift (Stokes drift) of the lifeboat in the propagation direction of the wave will be superimposed on this motion. In addition, there will be a drift caused by the wind force on the lifeboat. With thrust from the propeller, the net forward force will be positive part of the time, when the lifeboat is in a wave trough, and negative part of the time, when the lifeboat is close to a wave crest. A positive mean headway speed is ensured if the forward distance covered by the lifeboat when the net force is positive is greater than the backward distance when the net force is negative.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

7.5.3.3 Fulfilment of the headway speed requirements in [7.5.3.1] and [7.5.3.2] shall be demonstrated by full-scale offshore tests of the lifeboat in relevant sea states, i.e. in calm water and in the test sea state defined in [7.5.1.3], respectively.

7.5.3.4 A weather condition is defined, consisting of the test sea state given in [7.5.1.3] in combination with the largest possible average wave steepness and a concurrent 10-minute mean wind speed equal to or greater than 13 m/s. In this weather condition, the thrust and rudder capacity shall be sufficient to maintain a mean direction and a mean headway speed equal to or greater than 2.5 m/s regardless of the wave direction. Fulfilment of this requirement shall be demonstrated by means of a numerical simulator which is capable of extrapolating full-scale test results obtained in more relaxed sea states. The direction of the wind relative to the direction of the waves shall be varied between 0° and 20°. The requirement of a mean headway speed shall be fulfilled for both a fully loaded lifeboat and an empty lifeboat as defined in [7.4.3.1].

Guidance note: The average wave steepness of a sea state \( \left( H_s, T_p \right) \) is defined as

\[
S_p = \frac{2\pi H_s}{g T_p^2}
\]

where \( H_s \) denotes the significant wave height and \( T_p \) is the peak period. The largest average wave steepness \( S_p \) can be taken as 1/15 for \( T_p < 8 \text{ s} \) and 1/25 for \( T_p > 15 \text{ s} \) and can be interpolated linearly between these two limits. For a given value of \( H_s \), the solution of the largest average steepness \( S_p \) and the corresponding peak period \( T_p \) from the quoted equation may require an iterative procedure.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

7.5.3.5 In the 100-year sea state, the thrust and rudder capacity shall be sufficient to maintain a mean direction and a mean headway speed equal to or greater than 1 m/s. Fulfilment of this requirement shall be demonstrated by means of a numerical simulator which is capable of extrapolating full-scale test results obtained in more relaxed sea states. For this purpose, a simultaneous constant head wind equal to the 10-minute mean wind speed with a return period of 10 years shall be assumed. The direction of the wind relative to the direction of the waves shall be varied between 0° and 20°. The requirement of a mean headway speed shall be fulfilled for both a fully loaded lifeboat and an empty lifeboat as defined in [7.4.3.1]. The speed requirement applies to all wind directions and its fulfilment shall be demonstrated for wind directions of 0°, 45°, 90°, 135° and 180° relative to head wind.

7.5.3.6 The lifeboat shall have sufficient thrust and rudder capacity to allow the pilot to maintain control of the lifeboat in the 100-year sea state. Fulfilment of this requirement shall be demonstrated by means of a simulator which is capable of extrapolating full-scale test results obtained in more relaxed sea states. For this purpose, a simultaneous constant head wind equal to the 10-minute mean wind speed with a return period of 10 years shall be assumed. The direction of the wind relative to the direction of the waves shall be varied between 0° and 20°. The requirement shall be fulfilled for both a fully loaded lifeboat and an empty lifeboat as defined in [7.4.3.1].
Guidance note:
Maintaining control can be demonstrated by simulating a circular manoeuvre with a defined diameter in a 100-year sea state.
---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

7.5.3.7 The headway requirements given in [7.5.3.1] to [7.5.3.6] are summarized in Table 7-1.

Table 7-1: Summary of headway requirements

<table>
<thead>
<tr>
<th>Item</th>
<th>Sea state</th>
<th>Wind</th>
<th>Load condition for lifeboat</th>
<th>Minimum mean headway speed</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>[7.5.3.1]</td>
<td>Calm water</td>
<td>No</td>
<td>100%</td>
<td>3.0 m/s&lt;sup&gt;1)&lt;/sup&gt;</td>
<td>Full-scale test</td>
</tr>
<tr>
<td>[7.5.3.2]</td>
<td>Test sea state (Hs≥4 m)</td>
<td>No</td>
<td>0%</td>
<td>2.5 m/s</td>
<td>Full-scale test</td>
</tr>
<tr>
<td>[7.5.3.4]</td>
<td>Test sea state (Hs≥4 m)</td>
<td>U10≥13 m/s</td>
<td>100% and 0%</td>
<td>2.5 m/s</td>
<td>Numerical simulation</td>
</tr>
<tr>
<td>[7.5.3.5]</td>
<td>100-year Hs</td>
<td>10-year U10</td>
<td>100% and 0%</td>
<td>1.0 m/s</td>
<td>Numerical simulation</td>
</tr>
<tr>
<td>[7.5.3.6]</td>
<td>100-year Hs</td>
<td>10-year U10</td>
<td>100% and 0%</td>
<td>NA&lt;sup&gt;2)&lt;/sup&gt;</td>
<td>Numerical simulation</td>
</tr>
</tbody>
</table>

<sup>1)</sup> 1 m/s when towing an identical lifeboat
<sup>2)</sup> the pilot shall be able to maintain control

7.5.4 Engine

7.5.4.1 The engine shall keep running if the lifeboat is subject to excessive rolling as well as if the lifeboat is turned upside down.

7.5.4.2 The engine shall be operative when the lifeboat is flooded up to the centreline of the crank shaft.

7.5.5 Access

7.5.5.1 The lifeboat shall have a boarding ladder that can be used at any of the lifeboat's boarding entrances to enable persons in the water to board the lifeboat. The lowest step of the ladder shall not be less than 0.4 m below the lifeboat’s light waterline.

7.5.5.2 The lifeboat shall be so arranged that injured or unconscious people can be brought on board either from the sea or on stretchers.

7.5.6 Retrieval of occupants from a lifeboat at sea

7.5.6.1 The lifeboat shall be designed in such a manner that it shall be possible to transfer occupants from the lifeboat to a helicopter or to a larger rescue vessel.

Guidance note:
A hatch on top of the canopy and a platform adjacent to this hatch will allow the transfer of passengers in the sailing phase. The hatch and platform do not have to be located on top of the canopy. The hatch and platform can also be located in the aft. If the lifeboat is held up against the sea, the aft of the lifeboat will be the position on the lifeboat with the least motion.

The transfer of injured occupants at sea, particularly in bad weather, may influence which rescue and retrieval solutions are feasible. The time it takes before medical treatment can be provided may govern the design of the lifeboat in this respect and may set operational limitations. The time it takes before medical treatment can be provided may, in turn, depend on the availability of larger rescue vessels and standby vessels with equipment for the retrieval of occupants.
---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

7.5.6.2 For the transfer of occupants from the lifeboat in the sailing phase to a larger rescue vessel, it is beneficial if the lifeboat is designed to be compatible with the most recent generation of standby vessels that have docking systems for lifeboats.

7.5.6.3 To allow the transfer of occupants to a standby vessel, the lifeboat shall be equipped with a towline which can be thrown onto the sea surface and picked up by the standby vessel. Manual as well as automated heave out of the towline shall be possible. The towline system and the towline’s fastening in the bow of the lifeboat shall be designed in such a manner that the towline can withstand the loading from pulling the lifeboat to dock in the standby vessel.
7.6 Miscellaneous

7.6.1 Operations manual

7.6.1.1 An operations manual for the lifeboat shall be prepared. The operations manual shall address all the assumptions which have been made regarding the environment, release function, crew, occupants, manoeuvring, headway and other operational aspects. The operations manual shall also address how retrieval of the lifeboat using lifting appliances shall be carried out.

7.6.2 Training of personnel

7.6.2.1 Key safety personnel shall undergo training in the operation of the lifeboat at regular intervals.

Guidance note:
Regular training of key safety personnel under realistic conditions with respect to the weather and sea state will allow an assessment of the physical fitness of personnel for various duties onboard the lifeboat, including but not limited to the duties as a pilot and pumpman. The use of simulators for training key safety personnel can be considered. The training of key safety personnel should follow NOROG Guidelines No. 002: Recommended Guidelines for Safety and Emergency Preparedness Training.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

7.6.3 Maintenance

7.6.3.1 In order to ensure that the lifeboat functions as intended in the event of an emergency evacuation, the lifeboat shall be subject to periodic maintenance. For this purpose, a maintenance plan shall be prepared. The plan shall as a minimum contain the same elements as the maintenance procedure given in IMO MSC.1/Circ.1206.
SECTION 8 OCCUPANT SAFETY AND COMFORT

8.1 Introduction

8.1.1 General

This section provides occupant safety and comfort requirements for free-fall lifeboats during the various phases of operation.

8.2 Occupant safety

8.2.1 General

To ensure that no occupants will experience harmful acceleration-induced loads, the lifeboat designer must focus on the complex combination of many coincident relations, such as different body sizes and physical conditions, seating and harnesses, and adjacent structures.

A crucial aspect regarding the safety of personnel during launching is the ability of the seat and harness to ensure that a person is “very well locked to the seat”, and in particular that the relative motion between the occupant’s head/neck and upper part of the body is minimized. The suits and clothing that the combination of seat and harness is valid for shall be specified and documented.

8.2.2 Occupant properties

The lifeboat occupants will vary with respect to weight, length and body shape, as well as with respect to their medical and physical condition. As for their medical and physical condition, it can be assumed that all occupants have valid medical certificates allowing them to be offshore. The great majority of the occupants are not (pre-)injured when entering the lifeboat. The lifeboat and seats shall be designed for a range of persons within the minimum and maximum characteristic properties given in Table 8-1. The design of the seat arrangement should be as suitable as possible for the average occupant, yet such that there are seats suiting occupants with either minimum or maximum characteristic properties. At least one seat shall be designed for a person with minimum characteristic occupant properties. At least one seat shall be designed for a person with maximum characteristic occupant properties. The requirement for the design of the seats to suit a range of persons within the minimum and maximum characteristic properties in Table B1 can be fulfilled by using adjustable seats and seat belts fitting all sizes. The body measurements in Table 8-1 refer to Figure 8-1.

Figure 8-1 Occupant properties
Guidance note:
The medical/health examination that any offshore worker currently has to pass in order to obtain a new or renewed offshore certificate does not take into account relevant medical issues such as musculoskeletal-related disorders, which vary from one individual to another. These issues will have an influence on the probability and classification of injuries due to occupant acceleration loads.

The characteristic occupant properties given in Table 8-1 are exclusive of clothing, such that, in the design, the effects of clothing should be added to the quoted minimum and maximum properties. The same holds for the quoted properties of the Hybrid III median male dummy and RID3D dummy. In this respect, the effects of clothing should be taken as those pertaining to the clothing that the combination of seat and harness in the lifeboat is valid for.

The properties of the Hybrid III median male dummy are well-defined and serve to indicate what the properties of a typical occupant may amount to. Note, however, that the average occupant may well have characteristic properties which are somewhat larger than the properties of the Hybrid III median male dummy.

Characteristic occupants other than the ones dealt with in Table 8-1 are sometimes referred to. The Hercules-size large male has a weight of 120 kg and a height of 197 cm. The 5th percentile female has a weight of 49 kg and a height of 143 cm.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

8.2.3 Acceleration measures

8.2.3.1 The basis for evaluating acceleration-induced loads on the human body during the launch of a lifeboat consists of the acceleration components in relevant directions. The acceleration components $a_x$, $a_y$ and $a_z$ refer to the seat coordinate system given in Figure 8-2.

![Figure 8-2 The local (seat) coordinate system](image)

8.2.3.2 Various measures of acceleration are used as a basis for the acceptance criteria for occupant accelerations. The Combined Acceleration Ratio CAR, the Head Injury Criterion HIC and $G$ are examples of such measures. Definitions are given in [8.2.3.3] to [8.2.3.7]. Other human load measures used in acceptance criteria for human loads are defined in [8.2.4].

8.2.3.3 The CAR index is the maximum value of the time series of the SRSS (Square Root Sum of Squares) of the normalized $x$, $y$ and $z$ accelerations of a considered seat in the lifeboat

$$CAR = \max \left( \sqrt{\frac{a_x}{18g}}^2 + \sqrt{\frac{a_y}{7g}}^2 + \sqrt{\frac{a_z}{7g}}^2 \right)$$
in which 18 g, 7 g and 7 g are normalization constants for the accelerations \(a_x\), \(a_y\) and \(a_z\), respectively. The accelerations \(a_x\), \(a_y\) and \(a_z\) refer to the coordinate system given in Figure 8-2.

Two values of CAR are used, viz.

- \(\text{CAR}_1\) for out-of-seat acceleration, calculated from positive values of the \(a_x\) time series only
- \(\text{CAR}_2\) for into-seat acceleration, calculated from negative values of the \(a_x\) time series only.

**Guidance note:**
For calculating \(\text{CAR}_2\) for in-to-seat acceleration, it is recommended to use the expression for CAR as quoted. For calculating \(\text{CAR}_1\) for out-of-seat acceleration, it is recommended to reduce the normalization constant for \(a_x\) by 50% from 18g to 9g to reflect the immature state-of-the-art regarding how to treat the effects of out-of-seat acceleration on the human body at the time when this standard is issued. Hence, the use of

\[
\text{CAR}_1 = \max \left(\frac{a_x}{9g}, \frac{a_y}{7g}, \frac{a_z}{7g}\right)
\]

is recommended.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

8.2.3.4 For interpreting \(\text{CAR}_1\) and \(\text{CAR}_2\) from acceleration time series, acceleration data shall be filtered with no less than the equivalent of a 20 Hz low-pass filter. For filtering acceleration data, a Butterworth fourth-order filter shall be used where the frequency domain transfer function \(|H(f)|\) for the filter can be described by the equation:

\[
|H(f)|^2 = \frac{1}{1+(f/20)^2}
\]

where \(f\) is an arbitrary frequency in Hz (1/s).

8.2.3.5 The HIC\(_{36}\) index refers to an acceleration time series over a 36 ms-long time interval and is defined as

\[
\text{HIC}_{36} = \left\{ \frac{1}{t_2-t_1} \int_{t_1}^{t_2} \left[ a^2 + a_y^2 + a_z^2 \right]^{3/2} dt \right\}^{1/2}
\]

where \(a = \sqrt{a_x^2 + a_y^2 + a_z^2}\) and \(t_2 = t_1 + 36\text{ms}\).

HIC\(_{36}\) refers to accelerations of the human head and of the head of human surrogates in tests, rather than to accelerations of a particular point in the lifeboat itself.

8.2.3.6 Both the CAR index and HIC\(_{36}\) index exhibit variability from one launch of the lifeboat to the next. The characteristic value of the CAR index shall be taken as the 99% quantile in the long-term distribution of the CAR index in a launch at an arbitrary point in time. The characteristic value of the HIC\(_{36}\) index shall be taken as the 99% quantile in the long-term distribution of the HIC\(_{36}\) index in a launch at an arbitrary point in time.

8.2.3.7 \(G_x\), \(G_y\) and \(G_z\) are the maximum absolute values of the time series of the acceleration components \(a_x\), \(a_y\) and \(a_z\), respectively. Characteristic values are defined as the 99% quantiles in the respective long-term distributions in a launch at an arbitrary point in time.

8.2.4 Other human load measures

8.2.4.1 In addition to the acceleration measures, a number of other human load measures are used as a basis for the acceptance criteria for occupant loads. These other measures are based on forces in various parts of the human body. Definitions are given in [8.2.4.2] to [8.2.4.5]. Reference is made to Figure 8-3.

Human load measures as defined in [8.2.4.2] to [8.2.4.5] are usually measured in human surrogate tests, such as advanced instrumented dummy tests and PMHS (cadaver) tests, on the basis of applied representative acceleration time series, usually consisting of a pulse of duration 0.1 to 0.2 s. For accurate
interpretation of these human load measures from such tests, a sampling frequency equal to 20 000 Hz is recommended. Regarding the use of filters, reference is made to SAE J211.

Figure 8-3 Anatomical terms for the human body

Guidance note:
Cadaver tests and tests on volunteers are used to develop limiting values for human load measures and to correlate these limiting values with particular responses in specific instrumented test dummies.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

8.2.4.2 For neck loading due to moderate to severe frontal impacts, a set of four nondimensional neck injury parameters, denoted $N_{ij}$, are defined. The four components of the set are

- $N_{TE}$: tension-extension
- $N_{TF}$: tension-flexion
- $N_{CE}$: compression-extension
- $N_{CF}$: compression-flexion

and each component is calculated according to the following formula

$$N_{ij} = \frac{F_z}{F_{zc}} + \frac{M_{yc}}{M_{yc}}$$

in which

- $F_z$ = upper neck axial force measured in z direction
- $F_{zc}$ = critical force, in tension or compression
- $M_{Dy}$ = $M_y - D \cdot F_x$ = total moment
- $M_{yc}$ = critical moment in flexion or extension
- $M_y$ = upper neck moment measured about y axis
- $F_x$ = upper neck shear force as measured in x direction
- $D$ = distance between the force sensor axis and occipital condyle axis.
The referenced critical geometry, force and moment quantities take on the values specified in Table 8-2, depending on the occupant size.

8.2.4.3 For neck loading due to low-speed impacts, a set of four nondimensional neck injury parameters, denoted $N_{km}$, are defined. The four components of the set are

- $N_{FA}$: flexion-anterior
- $N_{EA}$: extension-anterior
- $N_{FP}$: flexion-posterior
- $N_{EP}$: extension-posterior

and each component is calculated according to the following formula

$$N_{km} = \frac{F_x + M_{OCY}}{F_{int} + M_{int}}$$

in which

$F_x$ = upper neck shear force measured in x direction
$F_{zc}$ = critical force, dummy independent
$M_{OCY} = M_y - D \cdot F_x$ = total moment
$M_{yc}$ = critical moment in flexion or extension
$F_{zc}$ = upper neck moment measured about y axis
$F_x$ = upper neck shear force as measured in x direction
$D$ = distance between the force axis and occipital condyle axis.

The referenced critical geometry, force and moment quantities take on the values specified in Table 8-2, depending on the occupant size.

Table 8-2 Critical geometry, force and moment values

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Condition</th>
<th>Hybrid III median male</th>
<th>5th percentile female</th>
<th>Hercules-size large male</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{zc}$ (N)</td>
<td>Tension</td>
<td>6806</td>
<td>4287</td>
<td>8799</td>
</tr>
<tr>
<td>$F_{zc}$ (N)</td>
<td>Compression</td>
<td>$-6160$</td>
<td>$-3880$</td>
<td>$-7964$</td>
</tr>
<tr>
<td>$M_{yc}$ (Nm)</td>
<td>Flexion</td>
<td>310</td>
<td>155</td>
<td>456</td>
</tr>
<tr>
<td>$M_{yc}$ (Nm)</td>
<td>Extension</td>
<td>$-135$</td>
<td>$-67$</td>
<td>$-198$</td>
</tr>
<tr>
<td>$F_{int}$ (N)</td>
<td>Anterior shear</td>
<td>845</td>
<td>532</td>
<td>1092</td>
</tr>
<tr>
<td>$F_{int}$ (N)</td>
<td>Posterior shear</td>
<td>845</td>
<td>532</td>
<td>1092</td>
</tr>
<tr>
<td>$M_{int}$ (Nm)</td>
<td>Flexion</td>
<td>88.1</td>
<td>44</td>
<td>114</td>
</tr>
<tr>
<td>$M_{int}$ (Nm)</td>
<td>Extension</td>
<td>$-47.5$</td>
<td>$-22$</td>
<td>$-61$</td>
</tr>
<tr>
<td>$D$ (m)</td>
<td></td>
<td>0.01778 $^{1)}$</td>
<td>0.01495</td>
<td>0.02022</td>
</tr>
</tbody>
</table>

$^{1)}$ For the upper neck load cell of the Hybrid III median male, as used in RID3D.

8.2.4.4 For abdomen and thorax loading, the resulting acceleration in the twelfth vertebrae is used as a parameter to assess the potential for injury.

8.2.4.5 For thoracic spine loading, the axial force $F_z$ in the twelfth vertebrae (thoracic level 12; T12) is used as a parameter to assess the potential for injury.

8.2.5 Characteristic values

8.2.5.1 The characteristic value of the Combined Acceleration Ratio (CAR) shall be taken as the 99% quantile in the long-term probability distribution of CAR in a launch at an arbitrary point in time. One probability distribution refers to the out-of-seat parameter CAR1 while another refers to the into-seat parameter CAR2. Accordingly, there is one characteristic value for CAR1 and one for CAR2. Likewise, for any other measure of human load, the characteristic value of that measure shall be taken as the 99% quantile in the long-term probability distribution of the measure in a launch at an arbitrary point in time.
8.2.6 Injury classification

8.2.6.1 Injuries are classified on the Abbreviated Injury Scale (AIS). There are seven AIS codes according to the classification on this scale, ranging from AIS0 to AIS6, see Table 8-3.

Guidance note:
The AIS scale is the most widely used injury scale in trauma research. It is an anatomically-based nonlinear severity scoring system, which can be used for every body region. The characteristics indicated in Table 8-3 refer to application to the brain and to the skeleton.

---end of guidance note---

<table>
<thead>
<tr>
<th>AIS Code</th>
<th>Injury</th>
<th>Examples of characteristics and indications</th>
<th>Brain/head injuries</th>
<th>Skeletal injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Non-injured</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Minor</td>
<td>Headache, mild concussion</td>
<td></td>
<td>Bruise or minor fracture</td>
</tr>
<tr>
<td>2</td>
<td>Moderate</td>
<td>Loss of consciousness for less than 1 hour</td>
<td>Moderate fractures, such as a long bone fracture or two rib fractures</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Serious</td>
<td>Loss of consciousness for 1 to 6 hours</td>
<td>Serious fractures, but not life-threatening, such as a crushed foot</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Severe</td>
<td>Loss of consciousness for 6 to 24 hours, nerve damage with a major loss of functioning</td>
<td>4 or more rib fractures on one side, 2 to 3 rib fractures with hemothorax or pneumothorax</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Critical</td>
<td></td>
<td>Fatal in the short term, such as a broken neck</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Unsurvivable</td>
<td></td>
<td>Decapitation, causing immediate death</td>
<td></td>
</tr>
</tbody>
</table>

8.2.7 Acceptance criteria for occupant acceleration loads

8.2.7.1 Each free-fall lifeboat shall be so constructed that no occupants will experience harmful loads or accelerations during any phase caused by any dimensioning or characteristic launching condition.

Guidance note:
In order to limit the accelerations that the occupants will experience during a launch, it will be beneficial to design the hull in a manner that will minimize the rotation (pitch) of the lifeboat when it penetrates the sea surface. Retardation of the lifeboat without any significant change of direction is expected to create a pleasant acceleration regime with respect to harmful loads.

---end of guidance note---

8.2.7.2 To ensure that no occupants will experience harmful loads or accelerations, the free-fall lifeboat designer must focus on the combination of seating, seat layout, harness and safety belt arrangements, dress code and clothing. The physical and medical condition of the occupant shall be taken into consideration when assessing the loads and accelerations.

8.2.7.3 Out-of-seat accelerations shall be minimized and preferably eliminated.

Guidance note:
The orientation of the seats in the cabin is a key parameter when this requirement is to be met.

---end of guidance note---

8.2.7.4 The potential for human injury shall be investigated in an early phase of a cabin design project. A simplified method for indicating the occupant acceleration load based on the CAR1 and CAR2 indices shall be applied for this purpose. It is a prerequisite for using CAR1 and CAR2 in this context that an optimal seat and harness arrangement is in place as required in [8.2.8].

8.2.7.5 The characteristic value of CAR1 for out-of-seat acceleration shall be less than 1.0.
Guidance note:
In establishing the characteristic value of CAR1 prior to verifying the fulfillment of this criterion, it is recommended to use a halved normalization constant for \( a_x \) in all calculations of CAR1, cf. the recommendation given in [8.2.3.3].

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8.2.7.6 The characteristic value of CAR2 for into-seat acceleration shall be less than 1.0.

8.2.7.7 The requirements in [8.2.7.5] and [8.2.7.6] shall be fulfilled for every seat in the cabin.

8.2.7.8 In the final cabin design, a detailed investigation of the acceleration loads based on tests on advanced instrumented dummies shall be executed. Principles and details of these tests and the premises for them are given in [8.2.7.9] to [8.2.7.13]. Acceptance criteria are given in Table 8-4.

Guidance note:
The average steepness of a sea state \((H_S, T_P)\) in deep water is defined as

\[
S_p = \frac{2\pi}{g} \frac{H_S}{T_P}
\]

where \( H_S \) denotes the significant wave height and \( T_P \) is the peak period. The largest average wave steepness \( S_p \) can be taken as 1/15 for \( T_P < 8 \) s and 1/25 for \( T_P > 15 \) s and can be interpolated linearly between these two limits. For a given value of \( H_S \), the solution of the largest average steepness \( S_p \) and the corresponding peak period \( T_P \) from the quoted equation may require an iterative procedure.

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8.2.7.9 A weather condition is defined, consisting of a sea state with a significant wave height equal to the 99% quantile in the long-term distribution of the significant wave height, combined with the largest possible average wave steepness and a concurrent 10-minute mean wind speed equal to the 99% quantile in the long-term distribution of the 10-minute mean wind speed.

8.2.7.10 Advanced instrumented dummy tests are based on acceleration time series, which may be determined from representative model-scale tests. With a view to reducing to a practicable level the number of tests necessary to arrive at characteristic values of the various human load measures, which are used in acceptance criteria for acceleration loads, it is recommended to apply a characteristic acceleration time series with three components \( a_x, a_y \) and \( a_z \) determined by means of model-scale tests or by means of a numerical simulator, for the situation that the lifeboat is launched in the weather condition defined in [8.2.7.9].

8.2.7.11 The characteristic values of the human load measures listed in [8.2.4] may be estimated by the values of the respective load measures that result from an advanced instrumented dummy test carried out on a median male dummy on the basis of the characteristic acceleration time series which is achieved as specified in [8.2.7.10].

8.2.7.12 Injury acceptance criteria are given for various parts of the human body. Criteria are given for the following body parts:

— abdomen, thorax and thoracic spine
— head
— neck.

8.2.7.13 Requirements for human load measures for various body parts are given in Table 8-4. For each measure listed, the characteristic value as estimated for a RID3D median male dummy according to [8.2.7.9] to [8.2.7.11] shall not exceed the limit specified in Table 8-4. The requirements given in Table 8-4 shall be fulfilled for every seat in the cabin. Conversions may be needed to obtain requirements for human load measures for dummies of different makes and sizes than the RID3D median male dummy.

Guidance note:
Most of the limits in Table 8-4 are established for a RID3D median male dummy. For the few limits established for other dummies, such as the Hybrid III median male dummy, it is assumed that these limits are also applicable for the RID3D median male dummy.

The intention behind the requirements set forth for the various human load measures in Table 8-4 is to satisfy the safety requirements given in [2.2.5] with respect to injuries at a level corresponding to AIS2 to AIS3 in such a manner that the relatively large variability in capacity from one occupant to another is accounted for. The requirements specified in Table 8-4 reflect the state-of-the-art at the time of issue of this standard when it comes to assessing the effects on the human body of the accelerations that occur during the launch of a free-fall lifeboat.
### Table 8-4 Requirements for human load measures for various body parts of an RID3D median male dummy

<table>
<thead>
<tr>
<th>Body part</th>
<th>Human load measure</th>
<th>Requirement for characteristic value of human load measure</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdomen, thorax and thoracic spine</td>
<td>T12_3ms (acceleration resultant)</td>
<td>60g</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T12_x (x acceleration)</td>
<td>60g</td>
<td>x acceleration of lowest vertebra in thoracic spine</td>
</tr>
<tr>
<td></td>
<td>T12_y (y acceleration)</td>
<td>20g</td>
<td>y acceleration of lowest vertebra in thoracic spine</td>
</tr>
<tr>
<td></td>
<td>T12 Fz_c</td>
<td>6700 N</td>
<td>Compression force in lowest vertebrae thoracic spine</td>
</tr>
<tr>
<td></td>
<td>Lap belt force</td>
<td>4000 N</td>
<td>Per belt, assuming two belts and equal forces in left belt and right belt. Requirement is only applicable in case of bad pelvis engagement, where lap belt penetrates abdomen.</td>
</tr>
<tr>
<td>Head</td>
<td>HIC36</td>
<td>650</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rotational accelerations</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$a_x$, $a_y$, $a_z$</td>
<td>2500 rad/s², 1800 rad/s²</td>
<td>if $\Delta \omega &lt; 30$ rad/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>if $\Delta \omega &gt; 30$ rad/s</td>
</tr>
<tr>
<td>Neck</td>
<td>NFx_a</td>
<td>788 N</td>
<td>Neck shear force, anterior</td>
</tr>
<tr>
<td></td>
<td>NFx_p</td>
<td>733 N</td>
<td>Neck shear force, posterior</td>
</tr>
<tr>
<td></td>
<td>NFy</td>
<td>900 N</td>
<td>Upper neck lateral shear force</td>
</tr>
<tr>
<td></td>
<td>NFz_c</td>
<td>$-1500$ N</td>
<td>Upper neck axial compressive force</td>
</tr>
<tr>
<td></td>
<td>NFz_t</td>
<td>1500 N</td>
<td>Upper neck axial tensile force</td>
</tr>
<tr>
<td></td>
<td>NMy_e</td>
<td>$-73$ N</td>
<td>Upper neck extension moment</td>
</tr>
<tr>
<td></td>
<td>NMy_f</td>
<td>190 N</td>
<td>Upper neck flexion moment</td>
</tr>
<tr>
<td></td>
<td>Nkm</td>
<td>1.1</td>
<td>Rear impact, whiplash motion</td>
</tr>
<tr>
<td>Femur</td>
<td>Femur compressive force</td>
<td>3800 N</td>
<td></td>
</tr>
<tr>
<td>Chest</td>
<td>Frontal viscous criterion</td>
<td>0.25 m/s</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Frontal compression</td>
<td>22 mm</td>
<td></td>
</tr>
</tbody>
</table>

#### 8.2.7.14 Requirements for human load measures for various body parts, applicable to the 5th percentile female and the Hercules-size large male, are given in Table 8-5. For each measure listed, the characteristic value as defined in [8.2.5.1] and as determined for a 5th percentile female shall not exceed the corresponding limit specified in Table 8-5 in those seats that are designated for the minimum occupant as specified in Table 8-1. Likewise, for each measure listed, the characteristic value as determined for the Hercules-size male shall not exceed the corresponding limit specified in Table 8-5 in those seats that are designated for the maximum occupant as specified in Table 8-1.
8.2.7.15 The requirements for human load measures given in Table 8-4 and Table 8-5 are requirements applicable during a launch in an emergency situation based on AIS2 to AIS3 as the critical injury level. For a launch in a training situation, it is common to apply stricter requirements than those given in Table 8-4 and Table 8-5. The requirements for HIC36 in Table 8-4 and Table 8-5 are conditional on seat and harness systems that meet the requirements in [8.2.8]. The requirements for HIC36 have to be used with caution, because the critical values of HIC36 are very sensitive to the actually selected seat and harness systems.

8.2.7.16 Although a crash test dummy often has a similar response to the human body along the vertical axis, this is not always the case for responses in other degrees of freedom, such as neck-bending moments. For any response quantity in question, it therefore needs to be demonstrated that the dummy and computational model used in the tests are capable of generating an appropriate representative response.

8.2.8 Seats and harnesses

8.2.8.1 The lifeboat shall be designed in such a way that any out-of-seat accelerations are minimized and preferably eliminated. The seat orientation shall be designed to allow for an into-seat force. The rotation of the lifeboat, affecting the occupants in the aft part of the boat, must be kept in mind when designing the seat orientation.

Guidance note:
In order to reduce or minimize the accelerations that the occupants will be exposed to during a launch, the designer should attempt to design the lifeboat hull in a manner that will minimize the rotation (pitch) of the lifeboat when it penetrates the sea surface, i.e. the lifeboat's change of direction when it penetrates the sea surface shall be as small as possible.

8.2.8.2 The seats and harnesses shall be fit for use for a range of people between and including the minimum and maximum specified in Table 8-1.

8.2.8.3 The harness shall be easily mounted, locked and regulated to fit all variations of body shapes between the minimum and maximum specified in Table 8-1, with a particular focus on rapid mustering and
personnel wearing survival suits but still providing safe fixation of the occupant. Reference is made to the body measures given in Table 8-1.

**Guidance note:**
The use of harness belts with take-up reels or other simple solutions which allow for fast buckling and fixation to the seat and prevent loose belts and tangles that may delay the evacuation is recommended.

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**8.2.8.4** The seats and harnesses shall provide adequate sideways fixation in order to safeguard the personnel in situations where sideways accelerations occur.

**Guidance note:**
Based on recent studies and tests, it is suggested that the seats should be equipped with a 5- or 6-point harness (1 or 2 crotch straps, 2 shoulder straps and 2 pelvic straps (lap belts)). It is essential for the intended function of the harness that the crotch belt, shoulder belts and lap belt can be tightened. It is important that the position of the lap belt does not depend on how the shoulder harness is adjusted. A correct lap belt should always grab below the iliac wings of the pelvis. The shoulder and lap belts can be combined into one if the combined belt can easily slide through the buckle. It is also strongly recommended that the shoulder belts are height adjustable, allowing the entire population in question to have belts tightly enveloping their shoulders.

Fixation systems other than the classical 5- and 6-point harnesses that are based on existing equipment without large modifications are foreseen to be adequate solutions to meet the fixation requirements.

Spacing is described in [8.3.2].

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

**8.2.8.5** The harness must be configured in such a manner that the occupant will not be at risk of slipping out underneath it.

**8.2.8.6** The designer shall describe what kind of clothing, including survival suits, the seats and harness are authorized for.

**8.2.8.7** To facilitate easy identification of belts and buckles and thereby facilitate fast fixation to the seat, contrasting colours shall be selected for harnesses and suits.

**8.2.8.8** The strength of seat and restraint systems shall be tested according to OLF LBP2-R001.

**8.2.9 Pre-injured occupants**

**8.2.9.1** Space as well as provision for ergonomic and safe handling of injured personnel shall be included in the design. Each lifeboat shall, as a minimum, allow for 1 injured occupant per 20 seats to be catered for. Each lifeboat shall in addition provide space for at least one injured occupant stretched out at full length.

**Guidance note:**
A description of the handling of injured personnel, with documentation of the transport, securing and fastening of the stretchers (or other means of transportation of patients), should be prepared.

In preparing this description, it is important to consider several topics and challenges, such as the maximum weight of seats or stretchers for transporting of injured personnel, the number of people necessary for lifting the seat or stretcher, and the ability of the seat or stretcher to float should it accidentally be dropped into the sea.

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**8.2.9.2** Seats for injured occupants shall have a different colour to that of ordinary seats and shall be clearly marked with the wording “Seat for injured person” or equivalent text.

**8.2.9.3** The seat module and space around it shall be in accordance with the requirements in [8.3.2] for free-fall lifeboat seats and shall in addition have the necessary space for the outstretched legs of an injured person. Solutions for space for injured persons need not be limited to seats in the traditional sense as long as they serve the purpose – such as stretchers.

**8.2.9.4** The strength of the seats shall meet the requirements for seats in free-fall lifeboats as given in [8.2.8.8].

**8.2.9.5** Every seat shall be equipped with suitable locking harnesses, capable of quick release under tension, to restrain the head/neck, body and feet during the launch.
**Guidance note:**
It is not evident that restraining the head will be required in practice, but the requirement in this clause ensures that it will be possible to restrain the head should the need arise.

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### 8.2.9.6
It should be possible to easily transport the seats from a temporary refuge or from the muster area into the lifeboat and secure them using a simple locking mechanism.

### 8.2.9.7
It should be possible to easily release the seats from their place in the lifeboat for safe transfer by helicopter or by other means for the retrieval of occupants. It shall be possible to lift releasable seats by means of a helicopter.

### 8.2.9.8
The seating arrangement shall be designed with attention to easy access for rescue personnel during the transfer of injured occupants into and out of the lifeboat.

### 8.3 Occupant comfort

#### 8.3.1 General

##### 8.3.1.1
The lifeboat shall be designed bearing in mind that the occupants may have to stay on board for several hours before they can be rescued. The comfort of the occupants while they are staying inside the cabin is therefore an important issue.

##### 8.3.1.2
This subsection deals with the comfort of the occupants in the standby phase and sailing phase. The standby phase is reckoned from when mustering is completed until the lifeboat is launched, and the sailing phase is reckoned from the time that launch has taken place.

##### 8.3.1.3
The mustering phase is reckoned from when mustering is initiated until mustering is completed. The mustering phase thus precedes the standby phase.

Some lifeboats are used as a muster area. Even for lifeboats which are used as a muster area, the mustering phase shall not be reckoned as part of the standby phase. Requirements for a muster area are given in [7.2.1] and apply regardless of whether mustering takes place outside or inside the lifeboat.

**Guidance note:**
It is implicit that when the lifeboat is used as muster area, the requirements for the muster area given in [7.2.1] become requirements for the lifeboat too.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

##### 8.3.1.4
The requirements given in this subsection serve to meet the needs of the occupants after mustering has taken place, i.e. in the standby phase and sailing phase. The comfort of the occupants in the mustering phase is dealt with through requirements given for a muster area in [7.2.1] and is not covered in this subsection.

##### 8.3.1.5
The interior of the cabin shall be of a colour which does not cause discomfort to the occupants.

#### 8.3.2 Occupant seating

##### 8.3.2.1
When designing occupant seating, the distance from the seat pan to the top of the head measured along the z axis of the local seat coordinate system shall not be less than 108 cm. The shoulder width shall not be less than 53 cm. The shoulder width shall be assumed distributed with 50% on either side of the seat’s centre line.

##### 8.3.2.2
At any point in time during the launch of the lifeboat, there shall be a minimum clearance of 20 cm between every occupant and the ceiling of the cabin. In verifying that this requirement is met, deformations of the ceiling as established from a structural analysis carried out for the structural design shall be taken into account, cf. [6.1.7.6].

##### 8.3.2.3
No body part shall hit a hard object at any point in time during the launch of the lifeboat. Thus the clearance between every occupant and any structure or object other than the ceiling of the cabin shall be minimum 10 cm in all relevant phases and conditions. The distance to neighbouring persons on each side is exempt from this requirement. In verifying that the requirement is met, deformations of the wall as
established from a structural analysis carried out for the structural design shall be taken into account, cf. [6.1.7.6].

Guidance note: To ensure that the requirement in [8.3.2.3] is met for different parts of the human body, the maximum body measures given in Table 8-1 can be assumed.

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8.3.2.4 With a 10 cm allowance for the effect of clothes, the shoulder width requirement in [8.3.2.1] implies a requirement for the centre-to-centre distance between two adjacent seats of minimum 63 cm.

8.3.2.5 A robust mock-up seating arrangement shall be built early, constituted by a minimum of 6 seats arranged in two rows, 3 seats in each row, with the intended spacing. The mock-up shall be tested using the full range of body dimensions given in [8.2.2]. For floating host facilities, the test shall be carried out for the host facility in the intact condition as well as in the damaged condition with trim and list. The purpose of this mock-up test is to demonstrate that:

- the seating and harness arrangements are ergonomically sound
- quick boarding can be ensured
- quick, ergonomic and reliable fixation to the seat is ensured
- the spacing is adequate.

8.3.3 Cabin temperature and fresh air quality

8.3.3.1 In both the standby phase and sailing phase, the fresh air quality inside the cabin must be acceptable.

8.3.3.2 It shall be documented, e.g. by full-scale testing, that the concentration level of CO₂ never exceeds 5000 ppm inside the cabin. This requirement applies to the standby phase and sailing phase. A requirement for the minimum fresh air supply in litres per minute per person shall be established based on the requirement for the CO₂ level in conjunction with the fresh air needed for breathing per person as a function of an adequate stress factor. This requirement shall be met in both the standby phase and sailing phase.

Guidance note: CO₂ is not directly injurious to health, but the concentration level will indicate the quality of the indoor air. A CO₂ level of 5000 ppm corresponds with that commonly required in building regulations for the inside of buildings on land.

The stress factor reflects the human activity level. The higher the activity level, the larger is the stress factor. The human activity level ranges from sleep and resting to hard work. The fresh air volume needed for respiration per person per hour increases with increasing activity level and thus also with increasing stress factor.

When the lifeboat is in the stowed position in the lifeboat station on the host facility, the air can be assumed to be supplied from the host facility. When the lifeboat has been launched and is in the sailing phase, the required air supply can be achieved by drawing air through the cabin by means of the running engine.

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8.3.3.3 To allow occupants to stand by in the lifeboat for a period of time before a launch, a system for temperature control in the cabin shall be implemented. This system need not be installed in the lifeboat itself, but can be a part of the host facility.

The requirement to implement a temperature control system can be waived when the lifeboat is not used as a muster area or the lifeboat is stowed within a temperature-controlled area.

8.3.3.4 The temperature control system shall be capable of keeping the inside temperature at between 16 and 22°C when the lifeboat is in the stowed position in the lifeboat station.

8.3.4 Lighting

8.3.4.1 The lifeboat shall have two separate lighting systems, denoted as System A and System B. When used prior to a launch, i.e. for standby, both systems shall be powered by the host facility’s emergency power supply.

8.3.4.2 Both systems shall have battery capacity capable of continuous operation for a period of at least 12 hours.
Guidance note:
To minimize the need for battery capacity, the use of new energy efficient technology such as LEDs is recommended.

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8.3.4.3 System A shall be designed with the aim of giving the lifeboat crew optimal working conditions.

8.3.4.4 System B shall be designed with the aim of giving all persons inside the lifeboat optimal conditions with respect to comfort and psychological effects.

Guidance note:
For occupants to be comfortable, warm colours should be used for System B.

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8.3.4.5 The illuminance level is measured in terms of luminous emittance. System B shall provide a luminous emittance of at least 75 lux 1.0 m above the floor. The uniformity of the illuminance shall be equal to or better than $E_{\text{min}}/E_{\text{mean}} = 0.5$, where $E_{\text{min}}$ denotes the minimum luminous emittance and $E_{\text{mean}}$ denotes the average luminous emittance.

Guidance note:
For System B, a luminous emittance of 100 lux is recommended, with the possibility of dimming. Too bright a light may be perceived as uncomfortable; however, it is important to provide sufficient light in the walkway and sufficient light to allow the occupants to read instructions.

To minimize the margin of error when measuring it, the illuminance level should be measured at a minimum distance of 0.5 m from the wall of the lifeboat.

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8.3.4.6 A manually controlled interior light shall be fitted inside the lifeboat, capable of continuous operation for a period of at least 12 h. It shall produce an arithmetic mean luminous intensity of not less than 0.5 cd when measured over the entire upper hemisphere to permit survival and equipment instructions to be read.

Guidance note:
Candela (cd) is the SI unit of luminous intensity: the candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency $540 \cdot 10^{12}$ Hz and that has a radiant intensity in that direction of 1/683 watt per steradian.

Lumen is the SI unit of luminous flux: luminous flux emitted in a unit solid angle (steradian) by a uniform point source having a luminous intensity of 1 candela.

Lux is the SI unit of illuminance: illuminance produced on a surface of area 1.0 m² by a luminous flux of 1 lumen uniformly distributed over that surface.

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8.3.5 Sanitary conditions

8.3.5.1 The design of the lifeboat shall take into account personal needs to vomit and visit the toilet during the standby and sailing phases.

8.3.5.2 Each seat in the lifeboat shall be equipped with sick bags that can be reached by each occupant when strapped to the seat and ready for free-fall evacuation. The sick bags shall not be transparent.

8.3.5.3 The sick bags shall be so designed that they can be sealed airtight after use.

8.3.5.4 Containers for the collection of sick bags shall be placed at different easily accessible locations in the lifeboat cabin. The containers shall have a watertight cover and be designed to withstand impact during the free-fall launch of the lifeboat.

8.3.5.5 Each container shall have a total capacity of minimum one sick bag per person on board.

8.3.5.6 The lifeboat shall be equipped with a toilet arrangement primarily for use during the sailing phase. Toilet facilities located outside but near to the lifeboat shall be available for use during the mustering and standby phases. All needs for toilet visits in the standby phase shall be approved by the lifeboat pilot and logged in the list of occupants to ensure that this list is always up-to-date.

Guidance note:
The toilet arrangement in the lifeboat may be of a simple type.
8.3.5.7  The sanitary arrangements shall have an easily accessible location and be screened or shielded from free access by a curtain or the equivalent.

8.3.5.8  The toilet container/tank shall have a watertight cover which can easily be used without leakage in any sea state that occurs.

8.3.5.9  In heavy weather conditions with a risk for injuries to any occupants moving around in the lifeboat, such movement is subject to the consent of the pilot.

8.4  Miscellaneous

8.4.1  Fire

8.4.1.1  A fire-protected lifeboat, when waterborne, shall be capable of protecting the number of persons it is designed to accommodate when subjected to a continuous oil fire that envelops the lifeboat for a period of not less than 10 minutes. Fulfilment of this requirement shall be documented by testing, see Sec.9.

**Guidance note:**
This requirement can usually be met by fitting the lifeboat with a water spray system. A water spray system with sufficient cooling capacity will allow the use of standard composite materials and will limit the need to insulate steel materials in the lifeboat structure.

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8.4.2  External colour

8.4.2.1  The lifeboat shall be of international or vivid reddish orange, or a comparably highly visible colour on all parts where this will assist detection at sea. The lifeboat shall be fitted with retroreflective materials where this will assist in detection.
SECTION 9  MODEL-SCALE TESTING AND FULL-SCALE TESTING

9.1  Introduction

9.1.1  General

9.1.1.1  This section outlines the general requirements for model-scale testing and full-scale testing of free-fall lifeboats.

9.1.1.2  For lifeboat systems, where the use of theoretical models and analysis tools raises challenges with respect to the prediction of responses in a free-fall launch, model-scale testing is vital in a design process. Unless reliable CFD analyses are available, carefully executed model tests at an appropriate scale are necessary to support the design of free-fall lifeboats. When adequate CFD analyses are available, such model tests are necessary to validate the CFD analyses.

9.1.1.3  Full-scale tests of free-fall lifeboats are carried out with the following two objectives:

— Prototype testing, where several tests on a single prototype lifeboat are executed in order to prove the design of a lifeboat type.
— Acceptance testing, which is usually limited to one launch per individual manufactured lifeboat in order to verify that the lifeboat has no functional or structural deficiencies.

Guidance note:
Acceptance testing is typically performed when installing the lifeboat on site, but can also be executed at an inshore or coastal location.
The execution of acceptance tests on site allows the entire lifeboat system to be tested, including the release arrangement and skid.
The execution of acceptance tests inshore will facilitate inspection of the lifeboat after the test.

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9.1.2  General guidance

9.1.2.1  DNV-RP-C205, Environmental Conditions and Environmental Loads, describes hydrodynamic model-scale testing in general and is used as a reference for this section.

9.1.2.2  Structural Finite Element Analyses (FEA) of the lifeboat should be performed prior to testing such that critical areas on the hull and canopy can be identified and subsequently highlighted in the tests. This applies prior to both model-scale testing and full-scale testing.

9.1.3  Extrapolation of test results

9.1.3.1  It is not always feasible to carry out model-scale tests and full-scale tests for the entire range of sea states of interest, e.g. because of limitations in the test facility that prevent the most severe wave conditions from being covered by the model tests. To the extent that results are needed for wave conditions not covered by the tests, extrapolation of results obtained in more relaxed wave conditions will be necessary. Numerical simulations can be used for this purpose provided an adequate numerical simulator is available.

Guidance note:
App.A provides guidance on how results from tests in less severe sea states can be parameterized and how interpreted mathematical relationships can be used to extrapolate to more severe sea states.

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9.2  Model-scale testing

9.2.1  Introduction

9.2.1.1  Model-scale testing can provide input to numerical analysis, e.g. in terms of hydrodynamic coefficients, and can assist in verifying and validating numerical analysis.

9.2.1.2  The model tests are meant to assist in establishing the characteristic loads, the characteristic accelerations and the characteristic pressures for use in the design of the lifeboat.
9.2.1.3 The model tests will also be used to document the obtained forward speed until water entry and after resurfacing to assess the required propulsion to ensure sufficient headway.

9.2.2 General requirements and simplifications

9.2.2.1 A model-test specification shall be established giving all details about the test objectives, test requirements and test execution.

9.2.2.2 Model-scale testing of free-fall lifeboats should be carried out using as large a model as possible and with a minimum lifeboat-model length of about 1 m. Multiple models or scales or both may be chosen depending on the focus area, e.g. the trajectories, pressures, accelerations, loads, maneouvrability or forward speed until water entry and immediately after resurfacing. The launching appliance used in the model tests shall be a model to scale of the launching appliance which is designed for the full-scale lifeboat.

Guidance note:
The minimum lifeboat-model length of about 1 m reflects the space required for instrumentation and the need to reduce the influence of scale effects. A smaller model may be used if it can be documented that the instrumentation and instrumentation cables do not affect the motion behaviour and the pressure distribution on the model. Typical model scales are in the range of 1:10 to 1:15, which usually allow the minimum model-length requirement to be met.

9.2.2.3 Testing shall include tests in calm sea. Depending on the purpose of the tests, testing in regular or irregular waves may be required in addition.

9.2.2.4 The main bulk of testing should be performed with long-crested waves. For areas with a high degree of multidirectional sea, the need for tests with short-crested waves should be evaluated. This evaluation should be based on the metocean specification for the actual site. With a view to possible serial production of lifeboats to be qualified for use in multiple locations, it might be necessary to base this evaluation on some representative envelope metocean conditions rather than on the metocean specification for a specific site.

9.2.2.5 The model-scale testing should include regular and irregular waves and wave approach headings of 0°, 45°, 90°, 135° and 180° where 0° is waves head-on in the launch direction (bow of lifeboat). This high number of headings is a basis for initial screening. Once more knowledge is available about which headings are critical, the number of headings can be reduced in subsequent tests.

9.2.2.6 The influence from current can in general be neglected because current velocities are usually small relative to launch velocities and wave particle velocities. The only exceptions to this are headway tests and maneouvrings tests, for which wind-generated current cannot be neglected.

Guidance note:
The potential influence of current on the wave profile, i.e., altered wave steepness and wave height due to the current, can usually be neglected, hence allowing separate tests of waves and current.

9.2.2.7 Wind tunnel tests to determine wind coefficients for the calculation of wind loads may be necessary if it is not possible to determine these coefficients otherwise, such as by CFD analysis. If wind coefficients are determined by CFD, such calculations shall be validated by wind tunnel tests. These coefficients are to be used as input to analytical models to calculate the lifeboat trajectory through air and as input to the model-test facility. It is assumed that the model-test facility can generate wind using fans and that the wind field and associated forces and moments can be monitored and controlled.

Guidance note:
Wind forces and moments obtained during model launch tests should be checked against the forces and moments obtained in wind tunnel tests. This can be done by measuring the effect of wind on the trajectory in air and on the lifeboat's rotational position (roll, pitch and yaw) at water impact and comparing them with solutions from numerical models based on quasi-static wind coefficients. Improved correspondence can be obtained by adjusting the wind speed or making minor geometrical changes on the lifeboat model. Wind coefficients must be obtained for a relevant range of apparent wind directions experienced on the skid and during free fall. Typically, 200 different directions (defined in terms of two spherical directions) are required, since the apparent wind direction depends on the lifeboat attitude and the velocity throughout the free-fall phase.

Numerical simulations based on quasi-static wind coefficients should be verified against unsteady CFD simulations in wind for some relevant conditions.
Due to the effect of local flow separation, wind coefficients depend on the external structural details, such as rails and sprinkler systems. Hence, these details must be accounted for in CFD models.

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9.2.2.8 A test using simultaneous waves and wind shall be performed, since wind will influence the relative hit angle between the water surface and lifeboat. Other means of obtaining changes in angle can be applied, but it must then be documented that these means do not unduly influence other results.

9.2.2.9 Steady wind should be included in the launch testing, whereas dynamic wind effects can be neglected due to the short launch time. The wind velocity may be taken as the relevant 10-minute mean wind speed at a height equal to half the launch height.

**Guidance note:**
The wind conditions at impact are in general best represented by the wind speed at a height equal to half the launch height. If local wind speeds prevailing at the skid, owing to the effects of a shelter and other (local) geometrical effects, influence the speed of the lifeboat when it leaves the skid, then these local wind speeds need to be accounted for.

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9.2.2.10 Wind directions should be collinear with wave directions for all the directions tested. For wave directions 0°, 45° and 90°, all tests should be performed including wind. Direction 0° is defined as waves head on in the launch direction (bow of lifeboat). Wind can be excluded from launch tests in the following wave conditions if it can be documented (for example by CFD) that the effect is negligible.

**Guidance note:**
The recommendation to use collinear wind and wave directions reflects that it is most likely that wind and wind-driven waves act collinearly. However, it should be kept in mind that it can sometimes be more critical if the wind acts on the lifeboat in a direction different from the wave direction, because a skew water entry may generate lateral accelerations.

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9.2.2.11 Initially, deep water can be assumed in tests; however the actual water depth at a site shall be taken into account if this has an effect on the wave kinematics and wave shapes.

9.2.2.12 For lifeboats to be used from host facilities in shallow waters, the tests shall be carried out for the actual water depth at the location in question.

**Guidance note:**
Shallow water is usually defined as water where the water-depth-to-wavelength ratio is less than 0.05.

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9.2.2.13 Free-fall lifeboats can be used for evacuation from both fixed and floating host facilities, and model tests of lifeboats shall be executed with due consideration of the effects of the actual type of host facility.

**Guidance note:**
There are basically two main types of host facilities which have to be considered, i.e. fixed structures and floating structures. The main types of fixed structures consist of GBS, jackets and jack-ups. The main types of floating structures consist of FPSOs, semis, TLPs and spar units. The TLP is restrained in heave, roll and pitch, but may have surge, sway and yaw motions at the same level as the other named floaters. The weather vaning capability of turret-moored FPSOs should be noted.

Special types of host facilities, like guyed towers and articulated towers should be treated like a TLP if the wave frequency horizontal deck/topside motions/accelerations are at the same level as those of a TLP.

---end---of---guidance---note---

9.2.2.14 For lifeboats on fixed offshore structures, the motion of the lifeboat station due to environmental loading can be neglected during model-scale testing.

9.2.2.15 For lifeboats on floating structures, the influence of floater motions shall be taken into consideration in the model-scale testing by either adjusting the launch height or varying the heel and trim skid angles, or both.

**Guidance note:**
Evaluations regarding the effect of wave-induced floater velocity and acceleration on the lifeboat impact angle and the relative velocity between the lifeboat and water particles in the wave may be beneficial. For large semi-submersibles, the effect of low frequency pitch and roll motion in harsh weather should also be evaluated.
If deemed important, model tests including at least the wave frequency motions of the floater (and thereby of the lifeboat station) should be performed. If not deemed important, the height adjustments and/or angle variations can be kept static throughout each test. No dynamic motion of the lifeboat station is in such case to be simulated.

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9.2.3 Recommended test execution when adequate computational fluid dynamics analyses are not available

9.2.3.1 Typical model scales for offshore structures are in the range of 1:30 to 1:100. Model-scale testing of free-fall lifeboats should be carried out with as large a model as possible and with a minimum lifeboat-model length of about 1 m. For free-fall lifeboats, a scale in the range of 1:10 to 1:15 is therefore expected to be necessary. The model-scale selection will typically be a trade-off between the absolute size of the model, the instrumentation and the wave conditions that are to be simulated. For further details about scaling and scaling effects, see DNV-RP-C205 [10.9]. In general, it is assumed that Froude's law of scaling applies.

Guidance note:
An air cavity usually develops behind the stern of the lifeboat as the lifeboat dives into the water. As long as this cavity is open to free air, i.e. a situation with ventilation prevails, it can be assumed that conventional Froude scaling applies and the behaviour of the cavity will be approximately as in full scale. However, when the cavity closes, the behaviour of the cavity in model scale will be different from the behaviour in full scale. For the closed cavity, the natural frequency of the cavity is proportional to the model scale and not to the square root of the model scale as it should have been according to Froude's law.

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9.2.3.2 The actual model shall be made of sufficiently strong material and should reflect the full-scale lifeboat with respect to global stiffness in so far as possible. Non-significant details may be omitted; however, details which may have an impact on hydrodynamic behaviour need to be included. Examples are: flanges, boat skids, rudders and nozzle systems. The model shall reflect the true COG position and inertias of the lifeboat and shall have opportunities to alter the longitudinal and transverse mass distribution due to variable loading such as that caused by variable manning. The effects and consequences of deviations from true properties and true details of the full-scale lifeboat which are necessary when the model is constructed shall be documented.

Guidance note:
It is difficult to obtain a lifeboat model which fully reflects the global stiffness of the full-scale lifeboat. In practice, typically, the external hull geometry is fully reflected, but not the girder system, such that a completely rigid model is used.

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9.2.3.3 Typical instrumentation which will be needed for these types of testing is:

— slamming/force panels (typical diameter: 40 to 60 mm)
— pressure cells (typical diameter: 2 to 6 mm)
— accelerometers (6 DOF) for registering vibrations and rigid body motions in at least two positions along the length of the lifeboat
— gyro
— camera or other optical tracking (above and under water).

Guidance note:
Relative wave probes fixed to the model are usually not used because they tend to excessively influence the test results. It is recommended to use at least three pressure cells or probes along the circumference of one typical cross section at a critical structural point. The difference pressure must be provided in the time domain such that the maximum of the combined time series can be further analysed.

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9.2.3.4 A set of regular waves and irregular sea conditions will have to be calibrated for use in the tests. Post calibration may be needed to check repeatability in the test basin. Wave modelling procedures for tests in regular waves and irregular sea are given in DNV-RP-C205, Sec.10.

9.2.3.5 The following are considered important with respect to wind modelling:

— Wind coefficients shall be determined from either wind tunnel testing, numerical analysis or available data.
— Simulating the correct wind forces and moments acting on the lifeboat is key. Wind velocities during the tests are therefore of less importance. Wind moments are of importance since these moments will influence the impact angle between the lifeboat and water surface.

— Initially, it is assumed that wind fans will have to be used and care should be taken to ensure a reasonably homogenous wind field with a reasonably correct vertical distribution of horizontal wind velocity.

9.2.3.6 The actual test preparations and execution should as a minimum follow the recommendations stated below, which are assumed to be given in the model-test specification:

— The calibration of sensors should be performed in conditions similar to actual test execution. Uncertainties, including the original accuracy of sensors (95% confidence values) should be quantified. Reference is made to e.g. ANSI/ASME PTC 19.1-1985 Part I, 1986 with respect to measurement uncertainty.

— Calibration and measurement should be carried out with the same data acquisition setup, including probes, wires, amplifiers, possible filters and an analogue-to-digital converter or sampling unit. If this is not the case, uncertainties due to a change in system components should be quantified.

— Caution should be exercised to avoid unnecessary influence from instrumentation cables. The effect of instrumentation cables should be documented.

— The waves in the basin should be calibrated after the wave measurement equipment has been carefully calibrated.

— The wave conditions need to be continuously measured during testing.

— Irregular wave testing should be performed with a minimum of 30 launches at random positions in the wave train. When the aim is to establish a probability distribution of a variable, a minimum of 50 launches at random positions are necessary.

— Alternatively, testing with conditioned launches, i.e. pre-selected launch points, could be used if substantiated that this is conservative for the estimation of the sought-after characteristic response values.

— The characteristics of the model should be within given accuracy limits for the centre of gravity, weight, geometry and radii of gyration.

Guidance note:
The following accuracy limits for lifeboat model characteristics are recommended:
- longitudinal centre of gravity (LCG): 0.1% of Lpp
- vertical centre of gravity (VCG): 1% of Lpp
- weight of lifeboat: 0.5%
- geometry: maximum value of 1% or 1 mm in model scale
- radii of gyration: 0.5% of Lpp
where Lpp is the length (between perpendiculars) of lifeboat.

9.2.3.7 The data acquisition, signal processing and analysis should as a minimum follow the recommendations given below.

a) All measurements and data should be presented in full-scale values based on Froude scaling.

b) Lower limits for sampling rates should typically be:
   — accelerometers: 800 Hz full-scale
   — accelerometers for vibrations: 1000 Hz full-scale
   — pressure sensors and slamming panels; 3000 Hz full-scale
   — wave measurements at 100 Hz. Assumed sufficient for model-scale.

c) For accelerometers, the sampling rate should preferably be 20 000 Hz and should not be less than 10 000 Hz full-scale when the acceleration data (time series) are to be used as input to numerical analyses and advanced instrumented dummy tests.

d) Filtering frequencies and types of filters. Typically, analogue Butterworth filters of order 4 can be used. The applied filters and cut-off frequencies must be documented and evaluated.
e) Calculate values from measured accelerations according to the specification in Sec.4 and App.A (CAR or other value). This specification should include filter frequencies and filter types. Obviously, the Nyquist frequency will limit filtered signals to below half the sampling frequency, depending on the filter characteristics, including the transition band.

f) The acceleration values should be calculated for the relevant seating arrangement (positions and angles). Usually, calculations for the pilot seat and the foremost and rearmost seats will be sufficient. Interpolation between these seats is acceptable assuming a rigid body lifeboat motion.

g) All estimated values should be presented with an interval showing the 95% confidence limits. This includes derived values and applies mainly to data from many tests in irregular sea. Bias errors due to the limited accuracy of transducers and data acquisition systems should be included.

h) Statistical post-processing should be done according to recognized methods.

i) Model-test results in calm water should be compared with similar results from full-scale testing. This can be used to assess possible scale effects due to e.g. ventilation, cavitation or flow separation.

9.2.4 Minimum level of testing

9.2.4.1 The minimum level of model-scale testing depends on the extent to which CFD analysis is used to determine the characteristic values of the loads, accelerations and pressures that act on the lifeboat during and after water entry. When CFD analyses are used to determine the governing characteristic values, a sufficient number of model launch tests shall be performed to allow for validation of the CFD analyses. When CFD analyses are not used for this determination, a sufficient number of model launch tests shall be performed to allow for determination of the governing characteristic loads, accelerations and pressures from the model test results. This mainly refers to testing in waves where a large number of wave conditions will have to be considered when the model test results are to be used as the basis for determining characteristic values for use in design.

Guidance note:
A wave condition is characterized by the significant wave height $H_s$, the peak period $T_p$, the wave spectrum, the mean wave propagation direction $\Theta_m$ and the directional spread (for short-crested sea). Details are given in Sec.3.

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9.2.4.2 A platform emergency evacuation via a lifeboat shall be safe even in severe weather conditions and from an intact host platform and damaged host platform. In this context, damage to the host platform refers to heel or tilt or both and is considered relevant for floaters only, not for fixed platforms.

9.2.4.3 Variations in launch height and launch angle caused by the heel and trim angles of the host facility shall be included in the test programme when the host facility is a floater. Motions of floaters and accidental conditions like heel and trim can be taken into account by varying the launch height and the heel and trim. The most probable values of wave frequency floater motion amplitudes shall be used as the basis for determining the adjusted launch height and heel/trim for both an intact floater and a damaged floater. It is possible to take into account the actual phasing of wave frequency motions relative to the wave profile. The trim and heel of the damaged host facility shall be set to ±17° unless other host-facility-specific values are known, in which case the two angles of +17° and -17° shall be investigated separately. Special attention shall be given to the situation in which the lifeboat is subject to a heel about its longitudinal axis when it is to be launched from the lifeboat station on a floater subject to heel and trim as specified.

Guidance note:
The most probable floater motion amplitudes within a specified short term wave condition can be found by assuming the motion amplitudes to be Rayleigh distributed.

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9.2.4.4 Model test conditions shall cover representative environmental conditions ranging from calm water to severe sea. This applies to both an intact host facility and damaged host facility. If possible within the capabilities of the model test facility, the most extreme model test conditions should be those of a sea state well beyond some severe characteristic sea states, but not necessarily as severe as the 100-year sea state. In an analogy with the characteristic ULS load being defined as the 99% quantile in the long-term distribution of the load during launch at an arbitrary point in time, the severe characteristic sea state may be defined as the sea state whose significant wave height $H_s$ is the 99% quantile in the long-term distribution of the significant wave height. For some North Sea locations, this characteristic significant wave height is approximately 8 m.
Table 9-1 recommends the minimum levels of launch testing in waves for a floating host facility. Table 9-2 recommends the minimum levels of launch testing in waves for a fixed host facility. Table 9-1 and Table 9-2 refer to the minimum level of testing recommended if no CFD analyses are available to determine the characteristic values of loads, accelerations and pressures. The actual number of tests specified in Table 9-1 and Table 9-2 will have to be judged based on the repeatability and scatter in results, but a minimum of three tests are recommended for calm sea tests whereas a minimum of five tests are recommended for the regular wave tests. For tests with specified hit points in regular waves, a minimum of three tests for each of four hit points are recommended, giving a total minimum of 12 tests. In order to establish probability distribution functions for loads and pressures in irregular wave tests with reasonable confidence, approximately 50 to 100 tests will be needed.

Guidance note:
The amount of testing indicated in Table 9-1 and Table 9-2 is very large and there must be thorough screening from case to case to reduce the amount of testing to a practicable level. Table 9-1 and Table 9-2 in principle contain full matrices of recommended tests. Depending on the response of interest, some of the indicated variable combinations and associated tests will not be relevant and can be left out.

The number of different wave headings to be considered may be reduced based on an initial heading screening with sensitivity checks. For a test of sufficient headway, it is not necessary to consider a following sea. For lifeboats on weather-vaning FPSOs, fewer wave directions need consideration than for lifeboats on other host floaters. If there are redundant lifeboat stations, the number of relevant wave directions can also be reduced.

The test matrices in Table 9-1 and Table 9-2 provide a systematic outline of the recommended minimum requirements for model-scale testing and can be optimized during the execution of the tests as the testing proceeds. Table 9-1 and Table 9-2 provide recommended minimum extents of test programmes for model-scale testing of free-fall lifeboats in both regular and irregular waves. In practice, the need to include tests in both regular waves and irregular waves in the same test programme will vary from case to case and will heavily depend on what the purpose of the testing is. When the purpose is to determine "worst case" loads through a controlled launch with water entry at the most unfavourable hit point in a wave, a test programme consisting of tests in regular waves only may seem natural, and tests in irregular waves can be left out. When the purpose is to determine probability distributions of one or more quantities of interest in connection with lifeboat launches, and in turn estimate characteristic values of these properties as required throughout this standard, then a test programme with tests in irregular waves needs to be set up. Tests in regular waves can be used for wave direction screening before the irregular wave tests.

The number of tests specified in the model test matrices in Table 9-1 and Table 9-2 can be reduced when model test data are available for the same lifeboat qualified for another location with corresponding, but not necessarily identical, environmental conditions. The number of tests can also be reduced when a numerical simulator is available to predict the lifeboat's behaviour.
9.2.4.6 A test with simultaneous waves and current can generally be omitted, see [9.2.2.6]. When considering headway and manoeuvring capabilities, results from current-only tests and wave-only tests may be superimposed.

9.2.4.7 A test with simultaneous waves and wind shall be performed, see [9.2.2.7] to [9.2.2.10].

9.2.5 Correlation and validation

9.2.5.1 After completion of the model tests, the model test results shall be validated by comparing the results with results from relevant analytical calculations or simulations or both. The validation work should include an attempt to explain key differences in the results and should provide advice regarding which parts of the model test results can be used in the design of the lifeboat. The validation work should also provide advice on possible additional testing or supplemental analytical work or both. A reference to and correlation with relevant full-scale testing should also be made.

9.3 Full-scale prototype testing

9.3.1 Introduction

9.3.1.1 Full-scale testing shall be executed and is considered a vital validation of analytical work and model-scale-testing. The level of such testing has to be decided based on the level and extent of the analytical work and model-scale testing.

9.3.1.2 For full-scale prototype testing, several tests are needed in order to document that the lifeboat is properly designed and fabricated, see Table 9-3.

9.3.1.3 Full-scale launch testing will, in this context, be offshore testing in a relaxed environment, or inshore or coastal testing in calm or benign environments. In order to compare full-scale tests to model tests or analytical solutions, it is preferable to test in a calm environment.

9.3.2 General requirements and simplifications

9.3.2.1 If full-scale launch testing on site is considered unsafe, difficult or impractical, full-scale tests can alternatively be executed inshore. Two types of test sites may be considered for such inshore testing:

— inshore, in protected (calm) waters
— a coastal location where tests may be executed with exposure to higher waves.

9.3.2.2 The actual wind, waves and current present during testing should be documented. As a minimum, the wind velocities and directions, the current velocities and directions and the wave heights and directions should be continuously recorded.

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Guidance note:
For tests carried out at a wharf or in a calm fjord, no instrumentation for recording metocean parameters is needed, except for recording wind, which is usually measured on the lifting vessel. For tests carried out offshore, simple measurements of metocean parameters are recommended.

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9.3.2.3 The prototype testing shall employ the actual drop or skid arrangements, as a minimum with respect to heights, angles and launch speeds. The lifeboat loading conditions which might be encountered in a real situation should also be tested. When the lifeboat is launched from a skid, it should be documented by measurements that the skid arrangement used during the launch test is sufficiently stiff such that skid deflections do not influence the test results.

9.3.2.4 In order to avoid human injuries it is required, full-scale prototype testing is required to be performed with no manning. The use of a remote control is recommended. Dummy weights shall be used to simulate the effects of different manning levels and weight distributions.

9.3.2.5 In order to verify simulations and calculations, prototype tests shall be carried out with instrumented crash test dummies.

9.3.3 Test execution

9.3.3.1 The prototype should reflect the actual global stiffness and mass distribution, inclusive COG and moments of inertia, that are intended to be experienced in a real evacuation situation offshore, such that the actual hydrostatics including metacentric heights are captured. The mass properties should be documented in order to enable comparison with simulations.

9.3.3.2 Wherever possible, the location of the instrumentation and measurements in the model-scale tests should be taken into account when planning the instrumentation of the full-scale testing. This applies especially to the locations of pressure panels and accelerometers. Findings from finite element analysis or from other analytical or numerical tools can also give guidance when planning the location of instrumentation.

9.3.3.3 The prototype lifeboat used for the full-scale test should as a minimum be equipped with the following instrumentation:

- System for registering rigid body motions and velocities (6 DOF) of the lifeboat during the launch, impact and up to the free float condition.
- System for registering and calculating accelerations at critical locations in the lifeboat.
- Instrumented slamming panels placed in critical areas as obtained from finite element analysis.
- System for measuring strain and stresses at critical areas.
- System for measuring deflections of the hull and canopy.
- Forward motion (video).
- For advanced instrumented dummy tests, a high-speed video of the dummy kinematics is needed. 1000 frames per second are usually sufficient.

9.3.3.4 The following issues regarding instrumentation, sampling, signal processing and analysis of the full-scale testing should be addressed:

- Accelerometers – the same as for model tests – at least three 3-axis accelerometers at three longitudinal positions. Sampling rate 800 Hz.
- For accelerometers, the sampling rate should preferably be 20 000 Hz and should not be less than 10 000 Hz when the acceleration data (time series) are to be used as input to numerical analyses and advanced instrumented dummy tests.
- Gyros for rotational motions (pitch and roll). Sampling 200 Hz.
- Additional measurements of deformations with similar sampling 200 Hz.
- Strain gauges at 1000 Hz.
- Slamming panels with a 3000 Hz sampling rate.
- System for measuring skid motions, e.g. induced by the motion of the lifeboat during the launch.
— Use digital video cameras to document the launch.
— Possibly include systems to monitor the engine, autopilot, rudder etc.
— The wind, waves and current should be measured or estimated during testing.
— The use of filters should be according to the specification of the estimation of characteristic values.
— Sensors should be mounted carefully in order to limit structural vibrations.

9.3.4 Minimum level of prototype testing

9.3.4.1 Prototype testing consists of one or more launch tests of a prototype lifeboat. The main bulk of prototype testing is assumed to be performed in calm water.

9.3.4.2 A minimum amount of prototype testing shall be carried out. The minimum amount of prototype testing consists of tests with test setups specified in Table 9-3. Table 9-3 applies to lifeboats on floating host facilities; hence for lifeboats on fixed host facilities, tests with variable launch heights and heel/trim conditions as specified in Table 9-3 can be omitted. Table 9-3 refers to two different load conditions, namely:

— empty lifeboat (lifeboat with the weight of three persons)
— fully loaded lifeboat (lifeboat with the weight of the full complement of occupants).

9.3.4.3 The launch height required in the prototype launch tests specified in Table 9-3 is 100% of the site-specific launch height \( h_L \) with adjustment for floater motions when the host facility is a floater. In addition to the tests specified in Table 9-3, a single prototype launch test with a launch height equal to 130% of the site-specific launch height \( h_L \) shall be carried out.

**Guidance note:**
The excess launch height test is described in IMO Resolution MSC.81(70). The excess launch height test will allow for useful benchmarking against experience with lifeboats designed in the past, since these have traditionally been subjected to comparable excess height tests as part of a type approval scheme. The required excess height test will also be a prerequisite for issuance of a SOLAS certificate for the lifeboat in accordance with IMO Resolution MSC.48(66), the International Life-Saving Appliances Code.

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9.3.4.4 For each test setup, the launch tests should be repeated at least once in order to indicate the variability of measurements.

9.3.4.5 After each prototype launch, structural inspections of the lifeboat shall be carried out, e.g. by visual inspection and coin-tapping, in order to identify any structural damage to the lifeboat structure.

9.3.5 Correlation and validation for prototype testing

9.3.5.1 A correlation and validation report which combines the results from the analytical work, the small-scale testing and the prototype testing shall be prepared.

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9.3.6 Fire test

9.3.6.1 The lifeboat shall be tested in water with burning oil on the sea surface. For this purpose, the lifeboat shall be moored in the centre of an area which is not less than five times the maximum projected plan area of the lifeboat. Sufficient kerosene shall be floated on the water within the area so that when ignited it will sustain a fire which completely envelops the lifeboat for a period of time equal to 10 minutes. The boundary of the area shall be capable of completely retaining the fuel.

The engine shall be run at full speed; however, the propeller need not be turning. Gas- and fire-protective systems shall be in operation throughout the fire test.

The kerosene shall be ignited. It shall continue to burn and envelop the lifeboat for 10 minutes.

During the fire test, the temperature shall be measured and recorded as a minimum at the following locations:

— at no fewer than 10 positions on the inside surface of the lifeboat
— at no fewer than five positions inside the lifeboat at locations normally taken by occupants and away from the inside surface; and
— on the external surface of the lifeboat.

The method of temperature measurement shall allow the maximum temperature to be recorded.

The temperature in the cabin shall not exceed 35°C at any point in time during the fire test.

The atmosphere inside the lifeboat shall be continuously sampled and representative retained samples shall be analysed for the presence and quantity of essential, toxic, and injurious gases and substances. The analysis shall cover the range of anticipated gases and substances that may be produced and which can vary according to the materials and fabrication techniques used to manufacture the lifeboat. The analysis shall indicate that there is sufficient oxygen and no dangerous levels of toxic or injurious gases and substances.

The pressure inside the lifeboat shall be continuously recorded to confirm that a positive pressure is being maintained inside the lifeboat.

At the conclusion of the fire test, the condition of the lifeboat shall be such that it could continue to be used in the fully loaded condition.

9.3.6.2 The fire test outlined in [9.3.6.1] may be waived for any totally enclosed free fall-lifeboat which is identical in construction to another lifeboat which has successfully completed this test, provided the lifeboat differs only in size and retains essentially the same form. The protective system shall be as effective as that of the lifeboat tested. The water delivery rate and the film thickness at various locations around the hull and canopy shall be equal to or exceed the measurements for the lifeboat originally fire tested.

9.3.7 Test of water spray system

9.3.7.1 The water spray system shall be subject to periodic testing to verify its maintained functionality and identify the need for maintenance. The water spray system shall be tested at least once per year.

9.3.8 Manoeuvring tests

9.3.8.1 Requirements for manoeuvring tests are given in [7.5.3].

9.4 Full-scale acceptance testing

9.4.1 Introduction

9.4.1.1 Acceptance testing shall be carried out for each manufactured lifeboat. The main purposes of the acceptance testing are:

— to document that the actual lifeboat does not have any structural deficiencies which could be detrimental in a real launch situation.
9.4.1.2 For full-scale acceptance tests, a minimum of one launch test per lifeboat shall be carried out. The loading condition shall be 100%, i.e. a lifeboat with the weight of its full complement of occupants.

9.4.1.3 For the acceptance testing, the same type of drop or skid arrangement shall be applied as the one which the lifeboat is to be used with when installed in the lifeboat station on the host facility. The launch height shall be the same as the launch height that applies when the lifeboat is launched from its permanent position in the lifeboat station.

9.4.1.4 In order to avoid human injuries, the test shall be performed with no occupants. The use of remote control is recommended. Dummy weights shall be used to simulate the 100% load condition.

9.4.1.5 If full-scale testing on site is considered unsafe, difficult or impractical, full-scale tests can alternatively be executed inshore. Two types of test sites may be considered for such inshore testing:

— inshore, in protected (calm) waters
— a coastal location where tests may be executed with exposure to higher waves.

9.4.2 Minimum level of acceptance testing

9.4.2.1 The level of instrumentation for acceptance testing may be limited to registering accelerations during the launch and water entry. However, it is recommended to monitor deformations of the canopy and hull too.

9.4.2.2 After the test, the lifeboat shall be subjected to a careful visual inspection. The inspection shall include the outside, inside, inside of all enclosed spaces and foundations for machinery, equipment, wind screens and seat supports. No visual damage, deformations or material failures are acceptable. FRP structures shall in addition be subjected to inspection by coin-tapping (or other equivalent technique such as ultrasound) to detect possible delaminations. Delaminations are not acceptable. Minor delaminations may be accepted based on special consideration. Inspections of FRP structures shall be carried out by an independent surveyor who is experienced in FRP construction. The extent of the inspections depends on the structural category, i.e. special, primary or secondary, with a higher level of detail for the former than for the latter.

Guidance note:
If possible, it is recommended to carry out the acceptance test before the hull is painted, as this will allow visual inspection as a method for detecting moderate delaminations which would otherwise have to be detected by other methods.

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9.4.3 Test of release system

9.4.3.1 Acceptance testing shall be performed in relation to all lifeboat release systems, including launching appliances and the retrieval system. This applies to all lifeboat release stations on the host facility. For this test, a weight equal to 110% of the fully loaded lifeboat shall be applied during the test in accordance with NORSOK R-002.

9.4.4 Lifeboat system testing

9.4.4.1 Full-scale acceptance testing shall include a test of all vital systems within each lifeboat on the host facility.

9.5 Commissioning testing

9.5.1 General

9.5.1.1 Commissioning tests shall be carried out when the lifeboat is installed on the host facility. Relevant requirements for commissioning tests are specified in NORSOK R-002 and NORSOK S-001 and shall be fulfilled. The test requirements in NORSOK R-002 appear in Annex A, and it is in particular noted that
NORSOK R-002 sets forth requirements for testing the launching and recovery appliances, including a static load test with a 220% load.

9.5.1.2 When acceptance testing according to [9.4] is carried out on the host facility, the acceptance tests can be coordinated with the commissioning tests and be planned such that they form some or all of the required commissioning tests.
SECTION 10 INSTALLATION

10.1 Lifting and retrieval appliances

10.1.1 General

10.1.1.1 The lifeboat can be installed in the lifeboat station using any capable lifting appliance such as a crane or a winch with a hook. Such a lifting appliance can be brought out temporarily for the sole purpose of installing the lifeboat or can be installed as a permanent piece of equipment in the lifeboat station.

10.1.1.2 The lifeboat station shall be equipped with a means of retrieval. The means of retrieval shall allow the retrieval of the lifeboat after test launches from the host facility and the reinstallation of the lifeboat upon completion of maintenance sessions ashore. The means of retrieval may be combined with the secondary means of launching in order to allow davit launching of the lifeboat, rather than free-fall launching, when the lifeboat is to be brought ashore for maintenance.

10.1.1.3 The means of retrieval shall be capable of lifting the empty lifeboat from the sea surface to its stowed position in the lifeboat station.

10.1.1.4 After launch testing by simulation, the means of retrieval shall be capable of bringing the lifeboat back to its original stowed position, ready for use in an emergency situation, without causing any damage to the lifeboat.

10.1.1.5 For details about the design of lifting appliances and means of retrieval, see NORSOK R-002, Annex A, and to DNV Standard for Certification No. 2.22.

10.1.2 Maintenance

10.1.2.1 A maintenance plan shall be prepared for any lifting appliances and means of retrieval installed in the lifeboat station to ensure adequate periodic maintenance. For details, see NORSOK R-002 and IMO MSC.1/Circ.1206.
SECTION 11  EQUIPMENT

11.1 Requirements for equipment

11.1.1 General

11.1.1.1 This section provides requirements for equipment which is part of the lifeboat system or which is installed in a free-fall lifeboat.

11.1.1.2 All items of equipment which are to be mounted in the lifeboat shall be mounted in such a manner that they do not come loose due to vibrations.

11.1.2 Launching and recovery appliances

11.1.2.1 Each lifeboat shall be arranged with primary and secondary means of launching. In addition, a means of retrieval shall be provided to recover the lifeboat from the water to the host facility.

11.1.2.2 Launching and recovery appliances for lifeboats shall comply with NORSOK R-002, Annex A.

11.1.2.3 Launching and recovery appliances shall be designed for simplicity and fail-safe operation and to reduce the risk of human errors during maintenance, drills and emergency situations.

11.1.2.4 Launching and recovery appliances shall be so designed and constructed that only a minimum amount of routine maintenance is necessary. All parts requiring regular maintenance by the platform crew shall be readily accessible and easily maintained.

11.1.2.5 Launching and recovery appliances and their attachments shall be of sufficient strength to withstand a static proof load in a test of not less than 2.2 times the maximum working load, where the maximum working load shall be taken as the expected load from the fully equipped lifeboat plus the expected load from the number of occupants associated with the load conditions, which are specified in [11.1.3.1] and [11.1.8.1] for primary means of launching and recovery appliances, respectively. The secondary means of launching is not meant for the emergency evacuation of personnel and is therefore exempt from fulfilling this requirement.

11.1.2.6 Launching and recovery appliances shall remain effective in a marine atmosphere, under temperature variations and under icing conditions.

11.1.2.7 The launching appliances shall be arranged so as to preclude the accidental release of the lifeboat in its unattended stowed position. If the means provided to secure the lifeboat cannot be released from inside the lifeboat, it shall be so arranged as to preclude boarding of the lifeboat without first being released.

11.1.3 Primary means of launching

11.1.3.1 The primary means of launching shall not depend on any means other than gravity or stored mechanical power which is independent of the host facility’s power supplies, to launch the lifeboat in either of the following two loading conditions:

— fully loaded lifeboat (lifeboat with the weight of the full complement of occupants)
— empty lifeboat (lifeboat with the weight of three persons).

11.1.3.2 On floating host facilities, the launching appliances shall be so arranged that the lifeboat can be launched when the host floater in a damaged condition is subject to trim and list and when the host floater in an intact condition is subject to accelerations and motions in the 100-year sea conditions. The trim and list when the host floater is in a damaged condition depend on the stability of the host facility and the possible loss of buoyancy in one or more supporting buoyant compartments. The trim and list for the damaged host facility shall be set to ±17° unless other host facility-specific values are known.

11.1.4 Release mechanism for the primary means of launching

11.1.4.1 The operation of the launch release mechanism shall be checked according to [6.1.8.3].
11.1.4.2 The load-bearing capacity of the release mechanism, including its connection to the lifeboat structure, shall be according to [6.1.8.3].

11.1.4.3 The design of the release mechanism for the primary means of launching shall be in accordance with ISO 12100.

11.1.4.4 The primary means of launching shall facilitate a way to keep the lifeboat secured in the stowed position when it is not in use and during training and maintenance. The securing arrangement shall be designed to avoid accidental release, cf. ISO 12100 and ISO 14119.

11.1.4.5 It shall be feasible to test the release function without exposing the crew in charge of performing the test to risk. It must be possible to carry out a realistic functional test which physically confirms that the release mechanism is functional.

11.1.5 Means of launch testing by simulation

11.1.5.1 The primary means of launching shall be subject to means of launch testing by simulation. The means of launch testing by simulation shall include facilities to perform a simulated release of a fully loaded lifeboat. It shall be feasible to test the release mechanism (simulation) without exposing the crew in charge of performing the test to risk. A realistic functional test which physically confirms that the release mechanism is functional shall be described.

11.1.6 Secondary means of launching

11.1.6.1 Each launching appliance shall be provided with a secondary means of launching for replacement and maintenance purposes. The secondary means of launching shall be equipped with at least one single off-load capability to release the lifeboat. The system shall facilitate the controlled lowering of the lifeboat to the sea, instead of free-fall launching, when the lifeboat is to be replaced or brought ashore for maintenance.

11.1.6.2 The secondary means of launching shall be based on gravity or power lowering, using the host facility’s power supplies, to launch the lifeboat in the following loading condition:

— empty lifeboat (lifeboat with the weight of three persons).

11.1.6.3 The secondary means of launching shall facilitate a means to keep the lifeboat secured in the stowed position when it is not in use and during training, testing of the release mechanism and maintenance. The securing arrangement shall be designed to avoid accidental release, see ISO 12100 and ISO 14119.

11.1.6.4 The secondary means of launching may be combined with the means of retrieval.

11.1.6.5 The secondary means of launching cannot be used of launch the lifeboat for emergency evacuation without reservation, because such use would imply that the lifeboat is being used as a davit-launched lifeboat. This is a use of the lifeboat which is beyond the scope of this standard, see [1.1.2.3].

To allow for the use of the secondary means of launching to launch the lifeboat for emergency evacuation would require the lifeboat to meet the requirements of an adequate standard for the design of davit-launched lifeboats in addition to meeting the requirements of this standard.

Owing to unresolved safety issues associated with emergency evacuation by means of davit-launched lifeboats, the use of the secondary means of launching to launch the lifeboat for emergency evacuation is in general not recommended.

11.1.7 Release mechanism for the secondary means of launching

11.1.7.1 The release mechanism for the secondary means of launching shall be designed in accordance with ISO 12100 and ISO 14119.

11.1.7.2 It shall be feasible to test the release mechanism when the lifeboat is secured in its stowed position without exposing the crew to risk. It must be possible to carry out a realistic functional test which physically confirms that the release mechanism is functional.
11.1.8 Means of retrieval

11.1.8.1 Each launching appliance shall be equipped with a means of retrieval. The means of retrieval shall be able to operate after test launches and maintenance sessions on the lifeboats ashore. The following loading conditions shall be considered:

— empty lifeboat (lifeboat with the weight of three persons)
— fully loaded lifeboat (lifeboat with the weight of the full complement of occupants).

11.1.8.2 The means of retrieval may be combined with the secondary means of launching.

11.1.9 Fire protection systems

11.1.9.1 The external equipment, including the engine exhaust system, shall not act as ignition sources.

11.1.9.2 Fire protection systems shall not prevent easy access to the lifeboat.

Guidance note:
Water- and foam-based systems are preferable to powder-based systems.

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11.1.10 Water spray system

11.1.10.1 The lifeboat shall be fitted with a water spray system.

11.1.10.2 Water for the system shall be drawn from the sea by a self-priming motor pump. It shall be possible to turn the flow of water on and off over the exterior of the lifeboat.

11.1.10.3 The seawater intake shall be so arranged as to prevent the intake of flammable liquids from the sea surface.

11.1.10.4 The system shall be arranged for flushing with fresh water and allow complete drainage.

11.1.10.5 The system shall be so arranged that it can be turned on and off from the manoeuvring positions.

11.1.10.6 The system shall be arranged so as to prevent ice accretion in the pipes and nozzles.

11.1.11 Engine

11.1.11.1 The engine shall be designed in such a manner that it will not be damaged if the lifeboat is temporarily turned upside down and the propeller becomes exposed to the open air. The engine shall also be designed in such a manner that it can draw air from sources other than the cabin, for example if the lifeboat is turned upside down.

Guidance note:
To enable the engine to draw air from sources other than the cabin, the engine must have at least one external air inlet in addition to any air inlet from the cabin.

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11.1.11.2 The engine shall be protected against overspeed when operated in the water entry phase due to a high probability of air ventilation. The engine shall be capable of operating without damage in 5 minutes without water cooling and with the propulsion system exposed to air.

11.1.11.3 Sufficient additional oxygen, e.g. supplied by air bottles, shall be provided for the lifeboat engine to be operated for 10 minutes without external air access.

11.1.11.4 All engines shall be fitted with a speed governor so adjusted that the engine speed cannot continuously exceed the rated speed by more than 10%.

11.1.11.5 A separate overspeed device is required in addition to the primary speed governor. The overspeed protective device may be substituted by an extra speed governor that is completely independent of the first governor and acts without delay.
11.1.11.6 If the primary speed governor fails, activation of the separate additional overspeed device shall ensure limitation of rpm. The overspeed device shall not depend on external energy sources.

11.1.11.7 The overspeed device shall be adjusted to ensure that the engine speed cannot exceed the maximum permissible speed as determined by the design, and in any case cannot go beyond 120% of the rated speed except for diesel engines driving generators, for which 115% of the rated speed applies.

11.1.11.8 For engines operating in areas defined as gas hazardous zones, an additional device that automatically shuts off the air intake in the case of overspeed shall be installed at each air inlet. If the engine draws air from the cabin, the corresponding shutting device shall be installed at the air inlet to the cabin if the air intake to the cabin is from the outside, but not if the air intake to the cabin is from an emergency air system such as air bottles. The emergency air system shall be automatically activated at the same time as the air intake to the cabin from the outside is shut off. The shutting device shall be activated at the same speed level as that used for the overspeed device required in [11.1.11.5]. For engines with turbochargers that can suffer overspeed due to a sudden interruption to the air intake, an additional shutting device should be installed between the turbocharger and engine.

11.1.11.9 The exhaust pipe shall be equipped with a spark arrestor.

11.1.11.10 Stored energy for power-starting the engine may be supplied by batteries. Each battery shall have its own charger. An alarm transmitted to a manned control station should be installed for use in case charging fails.

11.1.11.11 It shall be possible to hook up the engine to a cooling system while the lifeboat is in its stowed position in the lifeboat station, thus allowing the racing of the engine (not just idling) as part of periodic maintenance.

11.1.11.12 It shall be possible to start the engine in an ambient temperature of −15°C within 2 minutes of commencing the start procedure.

11.1.11.13 The engine and its accessories shall be designed to limit electromagnetic emissions.

11.1.11.14 The exhaust pipe shall be so arranged as to prevent water from entering the engine in normal operation.

11.1.11.15 The engine, transmission and engine accessories shall be enclosed in a fire retardant casing or other suitable arrangement providing similar protection. The engine compartment shall be watertight.

11.1.11.16 Air-cooled engines shall have a duct system to take in cooling air from, and exhaust it to, the outside of the lifeboat. Manually operated dampers shall be provided to enable cooling air to be taken in from, and exhausted to, the interior of the lifeboat.

11.1.12 Fuel tank

11.1.12.1 The fuel tank shall have a capacity which is sufficient to provide enough fuel to run the lifeboat at maximum speed for half an hour and to run it at 60% of maximum speed for 23½ hours.

11.1.12.2 The fuel tank shall always be full when the lifeboat is in its stowed position in the lifeboat station.

11.1.12.3 The fuel tank shall be equipped with shutoff valves. The fuel tank shall be so arranged that it allows the fuel to be sampled in accordance with NORSOK S-002.

11.1.13 Air intake

11.1.13.1 To achieve adequate air circulation in the lifeboat, the air intake for the engine and the air intake for the cabin air shall be located as far as possible from one another.

11.1.14 Electrical equipment

11.1.14.1 Electrical equipment which is located externally shall be provided with an enclosure which meets a weatherproof rating of at least IP66 and which shall be EX certified for Zone 1. Electrical equipment which is located inside the lifeboat shall be provided with an enclosure which meets a weatherproof rating of at least IP55. The nominal input voltage to electrical equipment shall not be greater than 230V.
Guidance note:
Details about the weatherproof rating in terms of the ingress protection (IP) rating are given in IEC60529. Details about explosive protection (EX) certification and hazardous zones are given in IEC60079.

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11.1.15 Manoeuvring positions and instrument panel

11.1.15.1 Two positions shall be provided for manoeuvring the lifeboat. All instruments and warning lamps shall be easily observable from both positions. It shall be possible to operate the VHF radio from both positions.

11.1.15.2 The two positions for manoeuvring the lifeboat shall be located side by side, one on the starboard side and one on the port side, with a common instrument panel between them. When the seats for the manoeuvring positions have one position for the free fall and another for the sailing phase, it will be beneficial if the instrument panel follows the seats when they are brought from one position to the other. A common manoeuvring handspike for engine and transmission, manoeuvrable from both manoeuvring positions and located between them, should be aimed for.

11.1.15.3 The order in which the instrumentation is arranged on the instrument panel should reflect the size and design in such a manner that easy observation and handling of the instrumentation are facilitated.

11.1.15.4 Table 11-1 gives a list of instrumentation and manoeuvring tools which as a minimum should be included at the two manoeuvring positions and in the instrument panel between the two manoeuvring positions.

Guidance note:
Table 11-1 indicates that the bypass valves for the release systems are on the starboard side and the pumps are on the port side. An alternative arrangement with both a valve and a pump of the independent systems on either side could be a better arrangement. When the portside operator is pumping, the starboard operator needs to open the valve and vice versa. This allows pumping from both operator positions, which provides safety in case one operator is incapable of pumping the release open. In addition, the correct pump will automatically be matched with the correct valve.

11.1.15.5 Adequate visibility from the manoeuvring positions shall be ensured.

Guidance note:
It is recommended to provide a windshield height of at least 40 cm. It is also recommended to avoid blind sectors as far as possible, thus allowing for as close to 360° visibility from each manoeuvring position as possible.

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Table 11-1 Minimum recommended instrumentation and manoeuvring tools and their placement

<table>
<thead>
<tr>
<th>Starboard side</th>
<th>Centre</th>
<th>Port side</th>
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</thead>
<tbody>
<tr>
<td><strong>Manoeuvring position 1</strong></td>
<td>Over-/under-pressure gauge for cabin</td>
<td>Engine revolution counter</td>
</tr>
<tr>
<td></td>
<td>Engine oil pressure gauge</td>
<td><strong>Manoeuvring position 2</strong></td>
</tr>
<tr>
<td>Steering wheel</td>
<td>Engine temperature gauge</td>
<td>Steering wheel</td>
</tr>
<tr>
<td></td>
<td>Dynamo for recharge light</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Handling of air bottles</td>
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<tr>
<td></td>
<td>Switch panel for light etc.</td>
<td></td>
</tr>
<tr>
<td>Bypass valves for two independent release systems</td>
<td>Engine start/stop</td>
<td>Hydraulic pumps for two independent release systems</td>
</tr>
<tr>
<td></td>
<td>Common VHF radio</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Common manoeuvring handspike for engine and transmission</td>
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<tr>
<td></td>
<td>Controller to activate release mechanism</td>
<td></td>
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<tr>
<td></td>
<td>Rudder indicator</td>
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<tr>
<td></td>
<td>GPS, digital compass or magnetic compass</td>
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</tr>
<tr>
<td></td>
<td>Valve to activate and shut-off water spray system</td>
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</tr>
<tr>
<td></td>
<td>Handle to activate heave-out mechanism for towline</td>
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</tr>
<tr>
<td></td>
<td>Fuel tank gauge</td>
<td></td>
</tr>
</tbody>
</table>
11.1.16 Maintenance of equipment

11.1.16.1 A maintenance plan shall be prepared for the equipment installed in the lifeboat to ensure adequate periodic maintenance. The maintenance plan shall address the issue of easy access for normal service of the engine, such as changes of oil and oil filters. The maintenance plan shall also address the issue of easy access to the engine fuel tank for cleaning and drainage. The plan shall as a minimum contain the same elements as the procedure for maintenance given in IMO MSC.1/Circ.1206.

11.1.16.2 Periodic maintenance of the fuel tank shall be carried out, including fuel sampling to verify adequate fuel quality and fuel replenishment.

11.1.16.3 Periodic maintenance of any freshwater tanks shall be carried out, including water sampling to verify adequate water quality and water replenishment.

11.1.16.4 Periodic maintenance of the means of launching, including the release mechanism, shall be carried out. This maintenance shall include inspection for rust and corrosion as well as the execution of associated repairs.

11.1.17 Miscellaneous

11.1.17.1 The requirements set forth in NORSOK S-001 shall be fulfilled with regard to the layout of the launching and recovery appliances, the outfitting of the lifeboat station, the access for boarding, and the visibility and lighting in the lifeboat station. Noise in the lifeboat station shall meet the noise requirements set forth in NORSOK S-002.

11.1.17.2 Emergency power should be provided for charging lifeboat batteries during stowage in the lifeboat station on the host facility. The disconnection point should be in the vicinity of the lifeboat and disconnection shall be automatic when the lifeboat is dropped or lowered.

11.1.17.3 Cabinet housing should be arranged for winches and consoles.

11.1.17.4 A heater should be provided for electric motors for winches in the lifeboat station. An optimal placement of the heater should be considered with a view to the conditions prevailing during icing.

11.1.17.5 At each seat, a pocket shall be provided within reachable distance with space for personal belongings such as glasses and sick bags.

11.1.17.6 A simple device, for example a nitrogen-filled GPS, shall be installed to show the pilot the lifeboat's position and direction immediately after the lifeboat has been launched.

11.1.17.7 The windscreen on the wheelhouse should be supplied with a windscreen wiper or equivalent equipment that can help to improve visibility for the pilot.

11.1.17.8 The lifeboat shall be fitted with sufficient watertight lockers or compartments to allow the storage of small items of equipment, water and food supplies.

11.1.17.9 The antenna for the VHF radio shall have arrangements for siting and securing the antenna effectively in its operating position.

11.1.17.10 A manually controlled exterior light shall be fitted. The light shall be white and capable of operating continuously for at least 12 hours with a luminous intensity of not less than 4.3 candela in all directions of the upper hemisphere. However, if the light is a flashing light, it shall flash at a rate of not less than 50 flashes and not more than 70 flashes per minute for the 12-hour operating period with an equivalent effective luminous intensity.

11.1.17.11 The lifeboat shall, where applicable, be provided with electrical short-circuit protection to prevent damage or injury.

11.1.17.12 The lifeboat shall be equipped with adequate propeller protection. The purpose of the protection is to safeguard persons in the water and prevent damage to the propulsion system caused by floating debris.
**Guidance note:**
Adequate propeller protection can be achieved by implementing a steering nozzle.

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11.1.17.13 The lifeboat shall be equipped with devices to assist in detecting the lifeboat at sea. Such devices include, but are not limited to:

- rocket parachute flares
- hand flares
- buoyant smoke signals
- waterproof electric torches
- daylight signalling mirrors
- a whistle or equivalent sound signal.

11.1.17.14 Equipment and appliances, which are installed in the lifeboat and are subject to deterioration with age shall be marked with a means for determining their age or the date by which they must be replaced, e.g. based on certificates for the equipment.
APPENDIX A  INTERPRETATION OF PROBABILITY DISTRIBUTION AND CHARACTERISTIC VALUES FROM EMPIRICAL DATA (INFORMATIVE)

A.1 Approach

A.1.1 General

A.1.1.1 This informative appendix outlines the methodology for interpreting probability distributions of relevant response quantities from empirical data. The empirical data consist of a set of observations of the quantity in question, e.g. from repeated model tests or repeated CFD analyses of lifeboat launches. An example of the methodology's application is given based on existing test data for a lifeboat model subjected to launch tests in the laboratory. The methodology is outlined in [A.1.2] and the example is given in [A.1.3].

A.1.1.2 The methodology is equally applicable when similar data are available from sources other than model tests or CFD analyses.

A.1.2 Methodology

A.1.2.1 The basis for interpreting the long-term probability distribution of a considered quantity X in a launch which is carried out at an arbitrary point in time, consists of observations of that quantity from model tests or CFD analyses of launches in irregular waves.

A.1.2.2 Observations of X are assumed to be available from a number of different sea states. Each sea state can be characterized by parameters such as the significant wave height and the peak period. For the purposes of simplicity, it is assumed below that each sea state is characterized by one parameter only, viz. the significant wave height HS.

A.1.2.3 For each considered HS, there is a set of n observations of the quantity X, obtained from n model tests where the lifeboat has been launched into a sea of irregular waves characterized by this particular HS. When the n observations of X are arranged in increasing order, they form an empirical distribution of X conditional on HS. To obtain a good grip on the distribution of X conditional on HS, the number of data values n should preferably be at least 50.

A.1.2.4 A parametric distribution function shall be fitted to the empirical distribution of X conditional on HS. Which parametric distribution function forms the best fit to the empirical distribution depends on what kind of quantity X is, for example peak pressure (defined as the maximum pressure throughout the duration of a launch test). Weibull, Gumbel and lognormal distributions are among the generic distribution types that should be tried out in the search for an adequate parametric distribution function to fit the empirical distribution. If a good fit to the entire empirical distribution cannot be obtained, it should be attempted to obtain a good fit to the upper tail of the empirical distribution. The fit of a parametric distribution function to the observed empirical distribution implies that the distribution parameters of the parametric distribution function are determined.

A.1.2.5 A visual inspection of the empirical cumulative distribution function of X conditional on HS, carried out on adequately chosen probability paper, may prove helpful in identifying the appropriate generic distribution type to be used for the fit. Guidance in this respect is provided in [A.2.2].

A.1.2.6 Tests or analyses to generate observations of the quantity X should be executed for a number of different HS values. The empirical distribution of X conditional on HS shall be established for each HS value and a parametric distribution function shall be fitted to the distribution or to its upper tail. The distribution parameters of the fitted distribution function can then be expressed as mathematical functions of the significant wave height HS. To get a good grip on these mathematical functions, tests or analyses for as many different HS values as possible should be carried out, still meeting the recommended minimum number of data values n per HS value. It is not recommended to limit the number of different HS values to less than three.

A.1.2.7 Once a parametric distribution function has been fitted to the empirical distribution of X conditional
on $H_S$, $F_{X|H_S}(x)$, then the sought-after unconditional long-term distribution of $X$ can be established by integration over all outcomes of the significant wave height $H_S$ according to the long-term distribution of $H_S$,

$$F_X(x) = \int F_{X|H_S}(x) \cdot f_{H_S}(h) \cdot dh$$

in which

$$f_{H_S}(h) = \frac{dF_{H_S}(h)}{dh}$$

is the probability density function for $H_S$.

Figure A-1 shows an example of the probability density function and the cumulative distribution function for $H_S$. As an example, the 99% quantile of $H_S$ is also shown. This is the value of the significant wave height which is exceeded 1% of the time. In Figure A-1, the exceedance probability of 1% can be identified as an area under the curve that represents the probability density function.

Figure A-1  Probability density function and cumulative distribution function for $H_S$

Figure A-2 shows a visualization of the conditional distributions of $X$, conditional on $H_S$, for various values of $H_S$.

Figure A-2  Probability density functions for $X$ conditional on $H_S$
Figure A-3 shows the resulting unconditional long-term distribution of X.

![Figure A-3](image)

**Figure A-3 Unconditional long-term distribution of X**

**A.1.2.8** The integration to determine $F_X(x)$ can be carried out numerically, or alternatively $F_X(x)$ can be established from the underlying distributions by Monte Carlo simulation. The characteristic value of X can be found as the 99% quantile in the unconditional long-term distribution $F_X(x)$ of X. An example is given in Figure A-3.

**A.1.3 Example**

**A.1.3.1** P is the peak pressure in a position on the canopy of a free-fall drop-launched lifeboat model, which has been tested in the laboratory. Measurements of P are available from tests in irregular sea for two different significant wave heights and also from tests in calm water, i.e. a total of three different $H_S$ values, viz. $H_S = 0.0$ m, $H_S = 6.8$ m and $H_S = 9.8$ m. The results indicate that the short-term distribution of the peak pressure conditional on the significant wave height is well represented by a Weibull distribution in the body and the upper tail. Let $X$ denote the peak pressure on the canopy normalized by the long-term mean value $\mu_P$ of the peak pressure, P. The short-term distribution of $X = P/\mu_P$ can then be represented by

$$F_{X|H_S}(x) = 1 - \exp\left(-\frac{x}{a}\right)^b$$

where the scale parameter $a$ and shape parameter $b$ are found to be

$$a = \exp(8.779 - 0.0003446 \cdot H_S^{0.0384}) / \mu_P$$

$$b = 4.0459 \cdot \exp(-0.1405H_S)$$

**A.1.3.2** These functional expressions for the parameters of the Weibull distribution have been obtained by interpreting results from Weibull fits to the bodies and upper tails of the cumulative distribution functions of the peak pressure conditional on the significant wave height $H_S$, see Figure A-4.

**A.1.3.3** A particular Norwegian Sea location is considered where the long-term distribution of the significant wave height is well represented by a Weibull distribution

$$F_{H_S}(h) = 1 - \exp\left(-\frac{h}{a}\right)^\beta$$

and where the scale and shape parameters are $a = 2.66$ m and $\beta = 1.407$. For this location, as a by-product of the integration in [A.1.2.7] and [A.1.2.8], the long-term mean value of the peak pressure on the canopy becomes $\mu_P = 5730.06$.

**A.1.3.4** The long-term distribution of $X$, $F_X(x)$, can be established by integrating the short-term distribution of $X$ over all realizations of $H_S$ according to the long-term distribution of $H_S$,

$$F_X(x) = \int_0^\infty F_{X|H_S}(x) \cdot \frac{dF_{H_S}(h)}{dh} dh$$

The result is shown in Figure A-5. The 99% quantile is $x_{99} = 2.00$ which gives a 99% quantile for the peak pressure $P_{99} = 5730 \times 2.00 = 11460$. 

A.1.4 Commentary

A.1.4.1 The example is based on data from tests using only three different values of the significant wave height $H_S$. The data for $H_S = 0$ m (calm water) are rather limited, much less than the preferred minimum of 50 data points, and the fitting of a straight line on Weibull scale to the upper tail of the conditional distribution of $X$ is somewhat ambiguous. For each of the two non-zero values of $H_S$, there are 50 data
points or more, and a visual inspection of the empirical distribution plots on Weibull scale indicates that the body and upper tail follow a straight line, such that a Weibull distribution is an appropriate distribution model.

However, with as few as only three $H_S$ values and with the somewhat uncertain fit (not particularly well-defined) of a Weibull distribution to the upper tail of the empirical short-term distribution for $H_S = 0$, in particular the interpreted functional relationship between the shape parameter $b$ of the short-term Weibull distribution and the significant wave height $H_S$ may be questioned. Improved support for the interpretation of this relationship could have been obtained by tests for more $H_S$ values than the three values investigated or by more model tests in calm water or both.

**A.1.4.2** The example shows an estimation of the characteristic value for a quantity for which a high realization of that quantity is unfavourable in design and for which the characteristic value is correspondingly defined as a high quantile, viz. the 99% quantile in the long-term distribution of the variable. Such high quantiles utilized to define characteristic values are common for quantities such as loads and accelerations. For quantities for which a low realization of the quantity is unfavourable in design, a low quantile is usually used to define the characteristic value, viz. the 1% quantile in the long-term distribution of the variable. An example of such a variable, where a low realization of the variable is unfavourable in design, is the distance between the lifeboat and the host facility when the lifeboat has been launched and has hit the water and resurfaced.

### A.2 Miscellaneous

**A.2.1 Long-term distribution of metocean parameters**

**A.2.1.1** Metocean data are often given in a condensed form in terms of the significant wave height $H_S$ and 10-minute mean wind speed $U_{10}$ with specific return periods such as 10, 100 and 1000 years. The long-term distributions of $H_S$ and $U_{10}$ can be derived from such condensed metocean data provided the generic distribution types for these distributions are known.

**A.2.1.2** The long-term distribution of the significant wave height $H_S$ is often a Weibull distribution,

$$F_{H_S}(h) = 1 - \exp\left(-\left(\frac{h}{\alpha}\right)^\beta\right)$$

Provided the Weibull distribution is the correct generic distribution type for $H_S$, the distribution parameters $\alpha$ and $\beta$ can be found by solving two equations with two unknowns, $\alpha$ and $\beta$. The two equations can be established from two different $H_S$ values with specified different return periods as given in the condensed metocean data, e.g. the $H_S$ values associated with return periods of 10 and 100 years. For each value $h$ of $H_S$ with an associated return period $T_R$, given in units of years, the cumulative probability is

$$F_{H_S}(h) = 1 - \frac{1}{N \cdot T_R}$$

where $N = 2922$ is the number of 3-hour stationary sea states in one year. When equated to $1 - \exp\left(-\left(\frac{h}{\alpha}\right)^\beta\right)$ this probability forms an equation in $\alpha$ and $\beta$. With two such equations established based on the two different $H_S$ values and their respective return periods, $\alpha$ and $\beta$ can be solved. The Weibull distribution assumption can be verified if $H_S$ values for three or more return periods are available and the corresponding three or more points ($\ln(H_S)$, $\ln(-\ln(1-F_{H_S}(H_S)))$) plot on a straight line.

**A.2.1.3** The long-term distribution of the 10-minute mean wind speed $U_{10}$ is often a Weibull distribution,

$$F_{U_{10}}(u) = 1 - \exp\left(-\left(\frac{u}{\alpha}\right)^\beta\right)$$

Provided the Weibull distribution is the correct generic distribution type for $U_{10}$, the distribution parameters $\alpha$ and $\beta$ can be found by solving two equations with two unknowns, $\alpha$ and $\beta$, in the same manner as outlined in detail for $H_S$. The cumulative probability associated with a value of $U_{10}$ whose return period is $T_R$ is

$$F_{U_{10}}(u) = 1 - \frac{1}{N \cdot T_R}$$

where $N = 52 596$ is the number of 10-minute periods in one year.
A.2.1.4 The same principles as those outlined above can be applied to establish the long-term distributions for \( H_S \) and \( U_{10} \) when the condensed metocean data support another distribution type than the Weibull distribution assumed in [A.2.1.2] and [A.2.1.3]. This requires that the appropriate expression for the cumulative distribution function is substituted for the Weibull distribution function in the expressions for \( F_{H_S} \) and \( f_{U_{10}} \) in [A.2.1.2] and [A.2.1.3].

A.2.2 Fitting of parametric distribution functions to empirical distributions

A.2.2.1 When selecting a generic distribution type and fitting its parametric distribution function to the empirical distribution of \( X \) conditional on \( H_S \), or to its upper tail, a number of trial distribution types should be considered, including but not limited to:

- Weibull distribution
- Gumbel distribution
- Normal distribution
- Lognormal distribution.

A visual inspection will often suffice to determine whether a particular distribution type will be an adequate model for an empirical distribution on hand.

A.2.2.2 The empirical distribution of \( X \) conditional on \( H_S \) is given in terms of \( n \) data pairs \((x_i,F(x_i))\), \( i = 1,...,n \), where the \( x_i \)'s are the \( n \) observed values of \( X \), e.g. obtained from \( n \) model tests in the laboratory. The \( x_i \)'s are sorted in increasing order and \( F(x_i) \) denotes the associated empirical cumulative probability. To calculate \( F(x_i) \), it is recommended to use the following expression when the Weibull distribution or the Gumbel distribution is considered as a distribution model to match the data:

\[
F(x_i) = \frac{i - 0.44}{n + 0.12}
\]

To calculate \( F(x_i) \), it is recommended to use the following expression when the normal distribution or the lognormal distribution is considered as a distribution model to match the data:

\[
F(x_i) = \frac{i - 0.375}{n + 0.25}
\]

A.2.2.3 The cumulative distribution function for the Weibull distribution reads

\[
F(x) = 1 - \exp\left(-\left(\frac{x}{a}\right)^b\right)
\]

where \( a \) and \( b \) are distribution parameters.

If the data pairs \((x_i,F(x_i))\) of the empirical distribution form a straight line in an \((\ln x,\ln(-\ln(1-F(x))))\) diagram, then the Weibull distribution will be an appropriate distribution model.

A.2.2.4 The cumulative distribution function for the Gumbel distribution reads

\[
F(x) = \exp(-\exp(-a(x - b)))
\]

where \( a \) and \( b \) are distribution parameters.

If the data pairs \((x_i,F(x_i))\) of the empirical distribution form a straight line in an \((x,\ln(-\ln(F(x))))\) diagram, then the Gumbel distribution will be an appropriate distribution model.

A.2.2.5 The cumulative distribution function for the normal distribution reads

\[
F(x) = \Phi\left(\frac{x - \mu}{\sigma}\right)
\]

where \( \Phi \) denotes the standard Gaussian cumulative distribution function and where \( \mu \) and \( \sigma \) are distribution parameters.

If the data pairs \((x_i,F(x_i))\) of the empirical distribution form a straight line in an \((x, \Phi^{-1}(F(x))))\) diagram, then the normal distribution will be an appropriate distribution model.
**A.2.2.6** The cumulative distribution function for the lognormal distribution reads

\[ F(x) = \Phi\left( \frac{\ln x - \mu}{\sigma} \right) \]

where \( \Phi \) denotes the standard Gaussian cumulative distribution function and where \( \mu \) and \( \sigma \) are distribution parameters.

If the data pairs \((x_i, F(x_i))\) of the empirical distribution form a straight line in an \((\ln x, \Phi^{-1}(F(x)))\) diagram, then the lognormal distribution will be an appropriate distribution model.
APPENDIX B  STRUCTURAL ANALYSIS AND CALCULATIONS USING THE FINITE ELEMENT METHOD (INFORMATIVE)

B.1  Introduction

B.1.1  General

B.1.1.1  The objective of this appendix is to provide methods and recommendations for calculating the response (with an emphasis on the finite element method (FEM)) of free fall-lifeboats to specified loads, surrounding environments and boundary conditions.

B.1.1.2  The aim of a structural analysis is to obtain the stresses, strains and displacements (denoted load effects in the following) in the structure as a result of loads and environmental conditions. The load effects are subsequently evaluated against failure criteria, see Sec.6. The following procedures are typically involved in such an analysis:

- procedure to calculate load effects in the structure based on the loads
- procedure to check for global or local failure.

B.1.1.3  If simple calculations cannot be performed to document the strength and stiffness of a structural component, a Finite Element analysis should be carried out.

B.1.1.4  Since an FEM analysis is normally used when simple calculations are insufficient or impossible, care must be taken to ensure that the model and analysis reflect the physical reality. This must be done by a careful evaluation of the input to, as well as the results of, the analysis.

B.1.1.5  FEM analysis tasks should be carried out by qualified engineers under the supervision of an experienced senior engineer.

B.1.1.6  The analysis should be performed according to a plan which has been defined prior to the analysis, and the approach should be documented.

B.2  Types of analysis

B.2.1  General

B.2.1.1  Analytical and/or numerical calculations may be used in the structural analysis. The finite element method (FEM) is presently the most commonly used numerical method for structural analysis, but other methods, such as finite difference or finite series methods, may also be applied.

Guidance note:
While the finite element method is applicable to a wide range of problems, analytical solutions and the finite series approach often put too many restrictions on the laminate lay-up, geometry etc., for composite and sandwich types of structures and may thus be insufficient in design.

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B.2.1.2  Though different types of analyses can be performed by means of FEM analysis, most analyses take the form of static analyses to determine the strength and stiffness of structures or structural components.

B.2.1.3  Only recognized FEM programs should be used. Other programs shall be verified by comparison with analytical solutions to relevant problems, recognized FEM codes and/or experimental testing.

B.2.1.4  Laminate analysis is an additional type of analysis that is applied to layered composites in order to derive the properties of a laminate from the properties of its constituent plies.

B.2.1.5  The structural analysis should be performed for all phases over the entire lifetime of the structure. Initial and degraded material properties should be considered if relevant.

B.2.1.6  It is of primary importance to the analysis of free-fall lifeboats to assess linear and nonlinear structural behaviour, structural strength and stiffness, as well as global and local buckling.
B.2.2 Static analysis

B.2.2.1 In a static analysis, structural parts are commonly examined in order to determine which extreme loads govern the extreme stress, strain and deflection responses.

B.2.3 Frequency analysis

B.2.3.1 Frequency analysis is used to determine the eigenfrequencies and normal modes of a structure or structural part.

B.2.3.2 The FEM program will normally perform an analysis based on the lowest frequencies. However, by specifying a shift value, it is possible to also obtain results for a set of higher frequencies around a user-defined frequency.

Guidance note:
The normal modes resulting from a frequency analysis only represent the shape of the deflection profiles, not the actual deflections.

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B.2.4 Dynamic analysis

B.2.4.1 Dynamic analysis should generally be performed when loads are time-dependent and/or when other effects such as inertia (and added mass) and damping forces are significant.

B.2.4.2 A dynamic analysis may be conducted in order to find the transient response of a structure due to prescribed, time-dependent loads or the “eigenvalues” (natural or resonance frequencies) of the structure.

B.2.4.3 In order to obtain an accurate transient analysis, a detailed structural model and small time steps should be used, in particular for rapidly varying loads.

B.2.4.4 For slowly varying loads, a quasi-static analysis may be applied. In such an analysis, inertia and damping forces are neglected and the corresponding static problem is solved for a series of time steps.

B.2.4.5 Dynamic analysis should be carried out in such a manner that findings from model-scale testing and corresponding loading scenarios are properly reflected.

B.2.5 Stability/buckling analysis

B.2.5.1 Stability/buckling analysis is relevant for slender structural parts or sub-parts. This is due to the fact that the loads causing local or global buckling may be lower than the loads causing strength problems.

B.2.5.2 The analysis is normally performed by applying a set of static loads. Hereafter, the factor by which this set of loads has to be multiplied in order for stability problems to occur is determined by the analysis program.

B.2.5.3 The need for a special buckling analysis should be assessed carefully in every case. In particular, the following aspects should be considered in this assessment:

— the presence of axial compressive stresses in beam or column-type members or structural elements
— the presence of in-plane compressive stresses or shear stresses in flat, plate-like elements
— the presence of in-plane compressive stresses or shear stresses in shell-like elements.

B.2.5.4 Two alternative approaches may be used to analyse buckling problems:

— analysis of isolated components of a standard type, such as beams, plates and shells with a simple shape
— analysis of an entire structure (or of an entire, complex structural component).

B.2.5.5 Buckling analysis of more complex elements or entire structures should be carried out with the aid of verified finite element software or the equivalent.

B.2.5.6 Initially, an “eigenvalue” buckling analysis should be performed assuming initial (nondegraded) elastic properties for the laminates and, for sandwich structures, for the core. This should be repeated with alternative, finer meshes until the lowest “eigenvalues” and corresponding “eigenmodes” are not
significantly affected by further refinement. The main purposes of this analysis are to clarify the relevant buckling mode shapes and establish the required mesh density for subsequent analysis.

**B.2.5.7** Careful attention should be paid to the correct modelling of boundary conditions.

**B.2.5.8** If the applied load exceeds, or is close to, the calculated elastic critical load, the design should be modified to improve the buckling strength before proceeding further.

**B.2.5.9** When geometrically nonlinear analyses are carried out, the results must be checked to assess buckling. To calculate the geometrical nonlinearity accurately in the analysis, it is important that the material stiffness specified as input to the analysis is representative and that the structural shape including curvatures, eccentricities, etc., is represented by the model.

For the assessment of the buckling and for calculating other load effects (deflections, stresses and strains), the design load effects may for simplicity be taken as the load effects of the design load, where the design load is determined as the characteristic load scaled by the load factor specified in this standard.

To assess the utilization of the material, a failure criterion appropriate for the respective material shall be applied, using the material factors and characteristic values of the material strength parameters specified in this standard.

Linear buckling calculations for complex structures must be used with great care and can hardly be justified as a method for verification. The only safe way to assess geometric effects in structures with complex geometries and mainly compressive forces is to apply nonlinear static analysis.

**B.2.6  Thermal analysis**

**B.2.6.1** Thermal analysis determines the temperature distribution in structural parts based on the initial temperature, heat input/output, convection, etc. This is normally a time-dependent analysis; however, it is usually not very time-consuming as only one degree of freedom is present at each modelled node.

**B.2.7  Global and local analysis**

**B.2.7.1** The global response of the structure is defined as the response (displacement and stability) of the structure as a whole.

**B.2.7.2** The local response of the structure is defined as the stresses and strains (and deformations) in every local part of the structure.

**B.2.7.3** The response of the structure should be calculated on a global or local level depending on the failure mechanism being checked and its associated failure criterion.

**Guidance note:**

The failure of the structure should generally be checked on the basis of the local response of the structure by the use of failure criteria for each failure mechanism as described in Sec.6. Buckling is generally checked on larger parts of the structure and based on average stresses over large areas. Under such conditions, a coarser analysis may be sufficient. However, if the finite element (FE) method is used to calculate buckling stresses, a very local analysis of the structure may be needed.

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**B.2.7.4** The advantage of an independent local model (or sub-model) is that the analysis is carried out separately on the local model, requiring less computer resources and enabling a controlled step-by-step analysis procedure to be carried out.

**B.2.7.5** The various mesh models must be compatible, i.e. the coarse mesh model (global model) should produce deformations and/or forces which are applicable as boundary conditions for the finer mesh model (sub-model). If super-element techniques are available, the model for local stress analysis may be applied at lower-level super-elements in the global model.

**B.2.7.6** Analysis of sub-models (fine mesh models) may be carried out separately by using the boundary deformations, boundary forces and local internal loads from the coarse model. Load data can be transferred from the coarse model to the local model either manually or, if sub-modelling facilities are available, automatically by the computer program.

**B.2.7.7** For global models based on composite or sandwich material, the actual detailed geometry of each part and important structural details from the joining of the different parts are crucial in order to obtain the
correct global deformations and account for any local or global effects of stiffness, as well as strength and resulting stress peaks.

B.2.7.8 Examples of global and local models of a free-fall lifeboat are given in Figure B-1 and Figure B-2.

![Figure B-1 Global model of a free-fall lifeboat](image1)

![Figure B-2 Model for detailed analysis of a wheelhouse](image2)

B.2.8 Material levels – composite/sandwich materials

B.2.8.1 The local response of the structure can in principle be analysed at the following different material levels:

— the “constituent level” corresponding to the fibre, matrix and core, separately
— the “ply level” corresponding to the individual layers in a laminate or the faces of a sandwich structure
— the “laminate level” corresponding to the whole laminate or sandwich structure.

B.2.8.2 Each failure mechanism can in principle be checked at any material level. However, due to the lack of theoretical knowledge or for practical reasons, it is not always possible to check a given failure mechanism at all material levels.

B.2.8.3 The local response of the structure should be analysed at a material level consistent with the failure criteria used in the failure analysis as described in Sec.6.
B.2.9 Nonlinear analysis

B.2.9.1 Static nonlinear analysis should be performed when geometrical and/or material nonlinearity are present and when linear and nonlinear analysis results are expected to differ.

B.2.9.2 Geometrical nonlinearity is associated with, e.g., large displacements and/or large strains, boundary conditions varying according to deformations, nonsymmetric geometry of structures and buckling.

B.2.9.3 Nonlinear material behaviour is associated with the stress–strain relationship. Following damage to the material, i.e. matrix cracking or yield, stress–strain relationships usually become nonlinear.

B.2.9.4 Structures made of composite (FRP) or sandwich material have smaller stiffness and generally exhibit a nonlinear behaviour at a lower load level than steel structures, thus indicating a stronger need for nonlinear analysis.

B.2.9.5 Structures with nonlinear materials should be checked against either early failure mechanisms, e.g. matrix cracking or yield, or ultimate failure, or both.

B.2.9.6 A decision whether to use a progressive, nonlinear failure analysis or a simplified (linear) failure analysis should be based on the failure modes of the structure or structural component in question and the failure mechanisms investigated.

B.2.9.7 For nonlinear problems, the following special considerations should be taken into account:
   — the analyst should make several trial runs in order to discover and remove any mistakes
   — the solution strategy should be guided by what is learned from the previous attempts
   — the analyst should start with a simple model, possibly the linear form of the problem, and then add the nonlinearities one by one.

B.3 Modelling

B.3.1 General

B.3.1.1 The FEM analysis model needs to reflect the actual methods used for lifeboat fabrication, for interconnection of the structural parts of the lifeboat, and for the interaction of the structural component with the rest of the structure.

B.3.1.2 The complexity and material application of present free-fall lifeboat solutions normally require a detailed FEM based on composite material and laminate theory.

B.3.1.3 Model behaviour should be checked against the behaviour of the structure. The following modelling aspects should be treated carefully:
   — loads
   — boundary conditions
   — static, quasi-static or dynamic problems
   — damping
   — possibility of buckling
   — isotropic or anisotropic material
   — temperature or strain-rate-dependent material properties
   — nonlinearity (due to geometrical and material properties)
   — membrane effects.

B.3.2 Input data

B.3.2.1 Environmental conditions should be converted into loads based on guidance to be found in Sec.3 and Sec.4, supported by relevant standards or guidelines.

B.3.2.2 The boundary conditions should be selected carefully in order to represent the nature of the problem in the best possible way. It should be demonstrated that the chosen boundary conditions lead to a realistic or conservative analysis of the structure.
B.3.2.3 Thermal stresses that result from the production process and from the in-service loading should be considered in all analysis.

B.3.2.4 Stresses due to swelling from absorbed fluids should be included if relevant.

B.3.2.5 The elastic properties of the materials constituting a composite structure should be taken to be according to DNV-OS-C501, Sec.4. In particular, time dependent stiffness properties based on the expected degradation due to environmental loading conditions should be considered. Local variations of these conditions should also be considered.

B.3.2.6 As an alternative to elastic constants, the stiffness matrix for orthotropic plies may be used.

B.3.2.7 It should be demonstrated that the estimated stiffness gives conservative results with respect to load effects. The choice of stiffness values may be different in the case of strength- and stiffness-limited designs.

B.3.3 Model idealization

B.3.3.1 The full vessel extent should be included in the global model.

B.3.3.2 The global analysis is intended to provide a reliable representation of the overall stiffness and global stress distribution in the primary members.

B.3.3.3 The global model should contain a primary structure that is easily identified with a clear load path which is not very sensitive to pressure variations.

B.3.3.4 The global analysis may be carried out using a relatively coarse mesh. Stiffened panels may be modelled by means of layered (sandwich) elements or anisotropic elements. Alternatively, a combination of plate and beam elements may be used. Modelling shall provide a good representation of the overall membrane panel stiffness in the longitudinal/transverse and shear directions.

B.3.3.5 The global model may be used to calculate nominal global (longitudinal) stresses away from areas with significant stress concentrations. The following features will induce significant stress concentrations:

- terminations of girder and bulkheads
- large penetrations, doors, windows, hatches
- sharp corners or abrupt transitions.

B.3.3.6 Small penetrations are normally disregarded in the global model. For consideration of local stresses in web frames, girders and other areas, fine mesh areas may be modelled directly into the coarse mesh model by means of suitable element transitions. However, an integrated fine and coarse mesh approach implies that a large set of simultaneous equations must be solved.

B.3.3.7 For local analysis, a local mesh refinement must be used. In such an analysis, the original mesh is stiffer than the refined mesh. When the portion of the mesh that contains the refined mesh is analysed separately, a correction shall be made so that the boundary displacements to be imposed on the local mesh are consistent with the mesh refinement.

B.3.3.8 If sub-models are used, these should be checked to ensure that the deformations and/or boundary forces are similar to those obtained from the coarse mesh model. Furthermore, the sub-model should be sufficiently large that its boundaries are positioned at areas where the deformation and stresses in the coarse mesh model are regarded as accurate. Within the coarse model, deformations at web frames and bulkheads are usually accurate, whereas deformations in the middle of a stiffener span (with fewer elements) are not sufficiently accurate.

B.3.3.9 The sub-model mesh should be finer than the mesh of the coarse model; for example, a small bracket is normally included in a local model, but not in a global model.

B.3.3.10 All the main longitudinal and transverse geometries of the hull should be modelled. Structural components not contributing to the global strength of the lifeboat may be disregarded in the global model. The mass of disregarded elements shall be included in the model.

B.3.3.11 Structural components not contributing to the global stiffness can lead to local or global stress
concentrations and it should be checked that omitting these parts does not lead to nonconservative results. Similarly, the omission of minor structures may be acceptable provided such an omission does not significantly change the deformation of the structure or give nonconservative results, i.e. too low stress.

**B.3.3.12** Continuous stiffeners should be included using any of the following options:

- lumping of stiffeners to the nearest mesh line
- inclusion of stiffeners in layered elements (sandwich elements), using 6- and 8-node shell elements for triangular and quadrilateral elements respectively
- inclusion of stiffeners as material properties (anisotropic material properties).

**B.3.3.13** Joints should be modelled carefully. Joints may have less stiffness than that inherited in a simple model, which may lead to incorrect predictions of global model stiffness. Individual modelling of joints is usually not appropriate unless the joint itself is the object of the study.

**B.3.3.14** The analyst should beware of the following aspects:

- for vibrations, buckling or nonlinear analysis, symmetric geometry and loads should be used with care since a symmetric response is not guaranteed for such problems. Unless symmetry is known to prevail, symmetry should not be imposed by the choice of boundary conditions.
- for crack analysis, a quarter point element can be too large or too small, thereby possibly making the results of mesh refinement worse
- the wrong choice of elements may lead to results that exhibit a dependence on Poisson’s ratio in problems whose solutions are known to be independent of Poisson’s ratio
- if plane elements are warped so that the nodes of the elements are not coplanar, results may be erratic and very sensitive to changes in the mesh
- imperfections of load, geometry, supports and mesh may be far more important in a buckling problem than in problems involving only a linear response.

**B.3.4 Coordinate systems**

**B.3.4.1** Different coordinate systems may be used to define the model and boundary conditions. Hence, the coordinate system valid for the elements and boundary conditions should be checked, e.g. by plots. This is particularly important for beam elements given that it is not always logical which axes are used to define the sectional properties.

**B.3.4.2** Regarding laminate elements, the default coordinate system often constitutes an element coordinate system, which may result in the fibre directions being distributed randomly across a model.

**B.3.4.3** Extreme care shall be taken when working with different relevant coordinate systems, i.e. global, ply-based, laminate-based, element-based and stiffener-based systems.

**B.3.5 Material models and properties**

**B.3.5.1** Several different material properties may be used across a model, and plots should be made and checked to verify that the material is distributed correctly.

**B.3.5.2** Drawings are often made using units of mm to obtain appropriate values. When the model is transferred to the FEM program, the dimensions are maintained. In such a case, care should be taken to set the material properties and loads correctly, as kg-mm-N-s is not a consistent set of units. It is advisable to use SI-units (kg-m-N-s).

**B.3.5.3** The material model used is usually a model for isotropic material, i.e. the same properties prevail in all directions. Note, however, that for composite materials an orthotropic material model has to be used to reflect the different material properties in the different directions. For this model, material properties are defined for three orthogonal directions. Defining this material means that the coordinate system for the elements has to be chosen carefully.

**B.3.5.4** Composite material, elastic constants: each laminate shall be described with the suitable set of elastic constants.
B.3.5.5 Sandwich structures: core materials are generally orthotropic and described by more than two elastic constants. However, most FEM codes can only describe isotropic core materials. If the elements applied in the FEM analysis do not allow values for all three parameters to be specified, the measured values for $G$ and $\nu$ should generally be used and the program should be allowed to calculate the $E$ value. In that case, the shear response of the core will be described accurately. However, in particular applications, in which core shear effects are negligible and axial stresses/strains are crucial, the correct $E$ values must be applied.

Guidance note:
For many core materials, experimentally measured values of $E$, $G$ and $\nu$ do not agree with the isotropic formula:

$$G = \frac{E}{2(1+\nu)}$$

---end---of---g-u-i-d-a-n-c-e---n-o-t-e---

B.3.6 Element types

B.3.6.1 Element types should be chosen on the basis of the physics of the problem.

B.3.6.2 For a specific structural part, several different element types and element distributions may be relevant depending on the type of analysis to be carried out. Usually, one particular element type is used to create an FEM model. However, different element types may be combined within the same FEM model. For such a combination, special considerations may be necessary.

B.3.6.3 1D elements consist of beam elements. Models with beam elements are quite simple to create and provide good results for framework structures. One difficulty may be that the sectional properties are not visible. Hence, the input should be checked carefully for the direction of the section and the numerical values of the sectional properties. Some FEM programs can generate 3D views showing the dimensions of the sections. This facility should be used, if present. Naturally, the stresses in the connections cannot be calculated accurately by the use of beam elements only.

B.3.6.4 2D elements consist of shell and plate elements. Shell and plate elements should be used for parts consisting of plates or constant thickness sub-parts. As shell elements suitable for thick plates exist, the wall thickness does not need to be very thin to obtain a good representation by such elements. These elements include the desired behaviour through the thickness of the plate. The problems applicable to beam elements also apply to shell elements, as the thickness of the plates is not shown. However, for most FEM programs, the thickness can be shown by means of colour codes, and for some programs the thickness can be shown by 3D views. The stresses at connections such as welds cannot be found directly by these elements either.

B.3.6.5 3D elements consist of solid elements.

B.3.6.6 A decision to use 2D or 3D analysis methods should generally be made depending on the level of significance of the through thickness stresses. If these stresses can be neglected, in-plane 2D analysis may be applied. Additionally, the analysis of certain laminate and sandwich structures may be simplified by a through thickness (cross section) 2D approach, in which the plane strain condition is assumed to prevail.

Guidance note:
In-plane 2D analysis is generally preferred when analysing relatively large and complex structures, in which through thickness stresses can be neglected. However, structural details with significant through thickness stresses, such as joints, require a more accurate analysis. In these cases, 3D or through thickness 2D (for components possessing plane strain conditions) approaches should be applied.

---end---of---g-u-i-d-a-n-c-e---n-o-t-e---

B.3.6.7 In the context of finite element analysis (FEM analysis) of laminate structures, one or both of the following element types should be applied:

- layered shell elements with orthotropic material properties for each layer
- solid elements with orthotropic material properties.
**Guidance note:**
There are two options for the solid elements: the modelling may be performed with (at least) two solid elements through the thickness of each ply. Alternatively, one may apply layered solid elements where the thickness of a single element includes two or more plies.

---end-of-guidance-note---

**B.3.6.8** In the context of FEM analysis of sandwich structures, one of the following element types or combinations should be applied:

- a single layer of layered shell elements through the thickness of the entire sandwich material
- (layered) shell elements for the faces and solid elements for the core. In this case, it may be desirable to compensate for the change in stiffness, or alternatively, in order to avoid overlapping areas, shell elements can be positioned adequately without the need to modify the material properties by using the element’s eccentricity property. Depending on the commercial package used, this option is not always available.
- solid elements for both faces and core.

**B.3.6.9** In an analysis of sandwich structures, special considerations should be taken into account, such as:

- elements including core shear deformation shall be selected
- for honeycomb cores, the material orthotropy should be accounted for, since honeycomb has a different shear modulus in different directions
- local load introductions, corners and joints should be checked
- curved panels with small radii of curvature should be analysed in 2D (through the thickness direction) or 3D to account for the transverse normal stresses not included in shell elements.

**B.3.6.10** By using solid elements, the correct geometry can be modelled to the degree of detail wanted. However, this may mean that the model includes a very large number of nodes and elements, so that the solution time will be very long. Furthermore, as most solid element types only have three degrees of freedom at each node, the mesh for a solid model may need to be denser than that for a beam or shell element model.

**B.3.7 Combinations**

**B.3.7.1** The three types of elements may be combined. However, as the elements may not have the same number of degrees of freedom (DOF) at each node, care should be taken not to create unintended hinges in the model.

**B.3.7.2** Beam elements have six degrees of freedom in each node – three translations and three rotations, while solid elements normally only have three – the three translations. Shell elements normally have five degrees of freedom – the rotation around the surface normal is missing. However, these elements may have six degrees of freedom, while the stiffness for the last rotation is fictive.

**B.3.7.3** The connection of beam or shell elements to solid elements in a point or line, respectively, introduces a hinge. This problem may be solved by adding additional ‘dummy’ elements to get the correct connection. Alternatively, constraints may be set up between the surrounding nodal displacements and rotations. Some FEM programs can set up such constraints automatically.

**B.3.7.4** Buckling analysis of stiffened plates and shells: when stiffened plate or shell structures are analysed for buckling, special attention shall be paid to the following failure modes:

- local buckling of laminate (plate) between stiffeners
- possible local buckling of individual plate-like elements in the stiffeners themselves
- overall buckling of the stiffened plate or shell, in which case separation (debonding) of the stiffener from the plate or the shell laminate must be explicitly considered.

**B.3.7.5** The finite element model shall be able to reproduce all relevant failure modes. Stiffener debonding shall be evaluated by the insertion of appropriate elements at the interface to monitor the tensile and shear forces that are transmitted across the bond, together with an appropriate criterion based on tests or relevant published data.
B.3.7.6 Buckling analysis for sandwich structures: sandwich structures may be exposed to highly localized buckling modes such as wrinkling and dimpling, in addition to more global modes. For simple stress states these local modes may often be checked using standard formulae.

B.3.7.7 The wavelengths for wrinkling are normally very short (often of the order of the sandwich thickness). If a direct FEM analysis of wrinkling is carried out, it is essential that a sufficiently fine mesh is used in the skin laminates, such that the mode shape is well represented. If each skin laminate is modelled using shell elements, the element size should not normally be greater than $\lambda/12$, where $\lambda$ is the buckling wavelength. The core shall be modelled with solid elements of similar size. The required element size shall be established using iterative calculations.

B.3.7.8 In performing FEM analysis of wrinkling, it is not normally necessary to model a large area of the structure provided the in-plane stress state in the skin is well represented. A portion of the panel extending over a few wavelengths is normally sufficient. The result is not normally sensitive to the size of the panel selected for modelling.

B.3.7.9 In the absence of detailed information about geometrical imperfections and their consequences, these may be allowed for by reducing the critical wrinkling stress by 40%. The face wrinkling stress in some textbook formulas may already include such allowance.

B.3.7.10 Wrinkling of skin laminates may be accompanied by a yielding of the core if the core is made of a ductile material. This may in turn lead to a reduction in the tangent stiffness of the core and a lowering of the critical stress for wrinkling. This is mainly a problem at points of load application and at joints, where the core experiences local loading, and may be avoided by adequate thickening of the skin laminate, the insertion of higher-strength core material locally or by other local design features. The adequacy shall be proved by testing or analysis unless previous experience shows the solution is adequate.

B.3.8 Element size and distribution of elements

B.3.8.1 The size, number and distribution of elements required in an actual FEM model depend on the type of analysis to be performed, the type of elements used and the type of material applied.

B.3.8.2 The choice of the mesh should be based on a systematic iterative process which includes mesh refinements in areas with large stress/strain gradients.

B.3.8.3 Generally, as beam and shell elements have five or six degrees of freedom in each node, good results can be obtained with a small number of elements. As solid elements only have three degrees of freedom in each node, they tend to be stiffer; hence, more elements are needed.

B.3.8.4 The shape and order of the elements influence the required number of elements. Triangular elements are stiffer than quadrilateral elements, and first-order elements are stiffer than second-order elements.

**Guidance note:**
The required number of elements and dependency on the element shape are illustrated in an example in which a cantilever is modelled by beam, membrane, shell and solid elements, see Figure B-3.

---e-n-d-o-f---g-u-i-d-a-n-c-e-n-o-t-e---

![Figure B-3 Cantilever](image)

---e-n-d-o-f---g-u-i-d-a-n-c-e-n-o-t-e---

Table B-1 gives the required number of elements as a function of the element type applied, as well as the corresponding analysis results in terms of displacements and stresses.

---e-n-d-o-f---g-u-i-d-a-n-c-e-n-o-t-e---
B.3.8.5 The model’s performance is closely linked to the type of elements and mesh topology used. The following guidance on mesh size, etc., assumes the use of 4-node shell or membrane elements in combination with 2-node beam or truss elements. The stiffness representation of 3-node membrane or shell elements is relatively poor and their use should be limited as far as practical.

B.3.8.6 The shape of 4-node elements should be as rectangular as possible, particularly where in-plane shear deformation is important. Skew elements will lead to inaccurate element stiffness properties.

B.3.8.7 Element formulation of the 4-node elements can require all four nodes to be in the same plane. Unintended fixation of a node can occur if it is “out of plane” compared to the other three nodes. The fixation will be seen as locally high stresses in the actual elements. Double curved surfaces should therefore be modelled with 3-node elements instead of 4-node elements. However, some structural analysis programs adjust the element formulation such that “out of plane” elements do not necessarily create significant errors in the structural analysis.

B.3.8.8 Provided 4-node element formulations include linear in-plane shear and bending stress functions, the same element size may be used for both 4-node shell elements and 8-node shell elements.

B.3.8.9 The use of higher level elements such as 8-node or 6-node shell or membrane elements will not normally lead to a reduced model size. 8-node elements are, however, less sensitive to element skewness than 4-node elements, and have no “out of plane” restrictions. In addition, 6-node elements provide significantly better stiffness representation than 3-node elements. The use of 6-node and 8-node elements is preferred.

B.3.8.10 The mesh size should be determined considering proper stiffness representation and the load distribution of sea pressure on shell elements or membrane elements.

B.3.8.11 The following guideline can be used for the element selection and distribution for the present design of a free-fall lifeboat in composite- or sandwich-type material:

— Laminate skins: can be modelled using shell elements. This is relevant for the inner and outer laminate in the canopy and for the outer laminate in the bottom. The shell elements should be layered and have different orthotropic material properties for each layer.
— Core material: (e.g. structured foam, balsa wood or syntactic foam) can be modelled using solid elements with orthotropic material properties. Buoyancy foam can also be modelled using solid elements. Limited shear strength or crushing resistance should be included in a nonlinear analysis.
— Sandwich structured composites: can be made using shell elements for the laminated skins and solid elements for the core.
— Girders and stiffeners can be modelled using beam elements.
— Brackets can normally be omitted in a global analysis.

One example of suitable element mesh with suitable element sizes is shown in Figure B-4.

Table B-1 Analysis of a cantilever with different types of elements

<table>
<thead>
<tr>
<th>Element type</th>
<th>Description</th>
<th>Number of elements</th>
<th>(u_y) [mm]</th>
<th>(\sigma_{x,\text{node}}) [N/mm²]</th>
<th>(\sigma_{x,\text{element}}) [N/mm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analytical result</td>
<td>Beam element, 2 nodes per element, 3 DOF per node, (u_x), (u_y) and (\theta_z)</td>
<td>-</td>
<td>1.9048</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>BEAM2D</td>
<td>Membrane element, 4 nodes per element, 2 DOF per node, (u_x) and (u_y)</td>
<td>10 x 1</td>
<td>1.9124</td>
<td>570</td>
<td>0</td>
</tr>
<tr>
<td>PLANE2D</td>
<td>Membrane element, 3 nodes per element, 2 DOF per node, (u_x) and (u_y)</td>
<td>10 x 1 x 2</td>
<td>0.4402</td>
<td>141</td>
<td>141</td>
</tr>
<tr>
<td>TRIANG</td>
<td>Membrane element, 3 nodes per element, 2 DOF per node, (u_x) and (u_y)</td>
<td>20 x 2 x 2</td>
<td>1.0316</td>
<td>333</td>
<td>333</td>
</tr>
<tr>
<td>SHELL3</td>
<td>Shell element, 3 nodes per element, 6 DOF per node</td>
<td>40 x 4 x 2</td>
<td>1.5750</td>
<td>510</td>
<td>510</td>
</tr>
<tr>
<td>SOLID</td>
<td>Solid element, 8 nodes per element, 3 DOF per node, (u_x), (u_y) and (u_z)</td>
<td>10 x 1</td>
<td>1.8980</td>
<td>570</td>
<td>570</td>
</tr>
</tbody>
</table>
B.3.8.12 The aspect ratio is the ratio between the side lengths of the element. The aspect ratio should ideally be equal to 1, but aspect ratios of up to 5 do not usually influence the results and are thus acceptable.

B.3.8.13 Element shapes should be kept compact and regular to perform optimally. Different element types have different sensitivities to shape distortion. Element compatibility shall be kept satisfactory to avoid poor local results, such as artificial discontinuities. Mesh should be graded rather than piecewise uniform, thereby avoiding a great discrepancy in size between adjacent elements.

B.3.8.14 The eccentricity of beam elements should be included. If the program does not support eccentricity of profiles, the modelled bending properties of the beams should include the attached total plate flange.

B.3.8.15 By applying composite material rather than steel, the structural ability to redistribute the stresses becomes significantly reduced; hence the attention to detail and need for a finer mesh must be enhanced.

Table B-1 Analysis of a cantilever with different types of elements (Continued)

<table>
<thead>
<tr>
<th>Element type</th>
<th>Description</th>
<th>Number of elements</th>
<th>$u_y$ [mm]</th>
<th>$\sigma_x$,node [N/mm$^2$]</th>
<th>$\sigma_x$,element [N/mm$^2$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TETRA4</td>
<td>Solid element, 4 nodes per element, 3 DOF per node $u_x$, $u_y$ and $u_z$</td>
<td>10 x 1 x 1</td>
<td>0.0792</td>
<td>26.7</td>
<td>26.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 x 2 x 1</td>
<td>0.6326</td>
<td>239</td>
<td>239</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40 x 4 x 1</td>
<td>1.6011</td>
<td>558</td>
<td>558</td>
</tr>
<tr>
<td>TETRA4R</td>
<td>Solid element, 4 nodes per element, 6 DOF per node</td>
<td>20 x 2 x 1</td>
<td>1.7903</td>
<td>653</td>
<td>487</td>
</tr>
</tbody>
</table>

Figure B-4 Global finite element model of a lifeboat (symmetric half of a lifeboat)

B.3.9 Element quality

B.3.9.1 The results achieved by a certain type and number of elements depend on the quality of the elements. Several measures for the quality of elements can be used; however, the most commonly used are aspect ratio and element warping.

B.3.9.2 Element warping is the term used for non-flatness or twist of the elements. Even a slight warping of the elements may influence the results significantly.

B.3.9.3 Most available FEM programs can check the element quality, and they may even try to improve the element quality by redistributing the nodes.
B.3.9.4 The quality of the elements in an automatically generated mesh should always be checked, in particular for the internal nodes and elements. It is usually possible to generate good quality elements for a manually generated mesh.

B.3.9.5 With regard to automatically generated high-order elements, care should be taken to check that the nodes on the element sides are placed on the surface of the model and not just on the linear connection between the corner nodes. This problem often arises when linear elements are used in the initial calculations and the elements are then changed into higher-order elements for a final calculation.

B.3.9.6 Benchmark tests to check the element quality for different element distributions and load cases are given by NAFEMS. These tests deal with beam, shell and solid elements, as well as static and dynamic loads.

B.3.9.7 The following requirements should be satisfied in order to avoid ill-conditioning, locking and instability:
- a stiff element shall not be supported by a flexible element, but rigid-body constraints should be imposed on the stiff element
- for plane strain and solid problems, the analyst shall not let the Poisson’s ratio approach 0.5 unless a special formulation is used
- 3D elements, Mindlin plate or shell elements shall not be extremely thin
- the analyst shall not use the reduced integration rule without being aware of possible mechanisms (e.g. “hourglass nodes”).

Guidance note:
Some of the difficulties associated with ill-conditioning, locking and instability can be detected by error tests in the coding, such as a test for the condition number of the structure stiffness matrix or a test for diagonal decay during equation solving. Such tests are usually made a posteriori rather than a priori.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

B.3.10 Boundary conditions

B.3.10.1 The boundary conditions applied to the model should be as realistic as possible. This may require the FEM model to be extended to include element models of structural parts other than the particular one to be investigated. One situation where this comes about is when the true supports of a considered structure have stiffness properties which cannot be well-defined unless they are modelled by means of elements that are included in the FEM model.

When such an extended FEM model is adopted, deviations from the true stiffness at the boundary of the structural part in question may then become only minor. As a consequence, the nonrealistic effects due to inadequately modelled boundary conditions are transferred further away to the neighbouring structural parts or sub-parts, which are now represented by elements in the extended FEM model.

B.3.10.2 The boundary conditions for the global structural model should reflect simple supports that will avoid built-in stresses. A three-two-one fixation, as shown in Figure B-5, can be applied. Other boundary conditions may be used if desirable. The fixation points should be located away from areas of interest, as the loads transferred from the hydrodynamic load analysis may otherwise lead to imbalance in the model. Fixation points are often applied at the centreline close to the aft and forward ends of the vessel.
B.3.11 Types of restraints

B.3.11.1 The types of restraints normally used are constrained or free displacements/rotations or supporting springs. Other types of restraints may be a fixed non-zero displacement or rotation or a so-called contact, i.e. the displacement is restrained in one direction but not in the opposite direction.

B.3.11.2 The way an FEM program handles the fixed boundary condition may vary from one program to another. One approach is to remove the actual degree of freedom from the model; another is to apply a spring with a large stiffness at the actual degree of freedom. The latter approach may lead to singularities if the stiffness of the spring is much larger than the stiffness of the element model. Evidently, the stiffness can be too small, which may also result in singularities. An appropriate value for the stiffness of such a stiff spring may be approximately $10^6$ times the largest stiffness of the model.

B.3.11.3 As the program must first identify whether the displacement has to be constrained or free, the contact boundary condition requires a nonlinear calculation.

B.3.11.4 Support conditions shall be treated with care. Apparently minor changes in support can substantially affect results. In FE models, supports are typically idealized as completely rigid, or as ideally hinged, whereas actual supports often lie somewhere in between. In-plane restraints shall also be treated carefully.

B.3.12 Symmetry and antimetry

B.3.12.1 Other types of boundary conditions are symmetric and antimetric conditions, which may be applied if the model and the loads possess some kind of symmetry. Taking such symmetry into account may reduce the size of the FEM model significantly.

B.3.12.2 The two types of symmetry that are most frequently used are planar and rotational symmetries. The boundary conditions for these types of symmetry can normally be defined easily in most FEM programs by using appropriate coordinate systems.

B.3.12.3 The loads for a symmetric model may be a combination of a symmetric and an antimetric load. This can be considered by calculating the response from the symmetric loads for a model with symmetric boundary conditions, and adding the response from the antimetric loads for a model with antimetric boundary conditions.

B.3.12.4 If both model and loads have rotational symmetry, a sectional model is sufficient for calculating the response.

B.3.12.5 Some FEM programs allow the response of a model with rotational symmetry to be calculated using a sectional model, even if the load is not rotational-symmetric, as the program can model the load in terms of a Fourier series.
B.3.13 Loads

B.3.13.1 The loads applied for the FEM calculation are usually structural loads, but temperature loads may also be relevant.

B.3.13.2 Structural loads consist of nodal forces and moments and surface pressure. Nodal forces and moments are easily applied, but may result in unrealistic local results. This is because no true loads act on a single point. Thus, the most realistic way to apply loads will usually be as pressure loads.

B.4 Documentation

B.4.1 Model

B.4.1.1 The results of an FEM analysis are normally documented by plots and printouts of selected extreme response values. However, as the structural FEM model used can be very complex, it is important to document the model itself too. Even minor deviations from the intention may give results that do not properly reflect reality.

B.4.1.2 The input for an FEM model must be documented thoroughly by relevant printouts and plots. The printed data should preferably be stored or supplied as files on a CD-ROM.

B.4.1.3 The results of an FEM analysis can be documented by a large number of plots and printouts, which can make it an overwhelming task to find out what has actually been calculated and how the calculations have been carried out.

B.4.1.4 The documentation of the analysis should clearly state which model has been considered, and the relevant results should be documented by plots and printouts.

B.4.1.5 The model aspects listed in [B.4.2] through [B.4.7] can and should be checked prior to the FEM analysis.

B.4.2 Geometry control

B.4.2.1 Verifying the geometric model by checking the dimensions is an important and often rather simple task. This simple check may reveal if numbers have unintentionally been entered incorrectly.

B.4.3 Mass – volume – centre of gravity

B.4.3.1 The mass and volume of the model should always be checked. Similarly, the centre of gravity should correspond with the expected value.

B.4.4 Material

B.4.4.1 Several different materials can be used in the same FEM model. Some of these may be fictitious. This should be checked on the basis of plots showing which material is assigned to each element, and by listing the material properties. Here, care should be taken to check that the material properties are given according to a consistent set of units.

B.4.4.2 Plots should be made and checked in order to verify that material properties, material types and plate thicknesses are distributed correctly.

B.4.5 Element type

B.4.5.1 Several different element types can be used, and here plots and lists of the element types should also be presented.

B.4.6 Local coordinate system

B.4.6.1 With regard to beam and composite elements, the local coordinate systems should be checked, preferably by plotting the element coordinate systems.

B.4.6.2 Verification of whether the many different relevant coordinate systems have been applied correctly shall be considered.
B.4.7 Loads and boundary conditions

**B.4.7.1** The loads and boundary conditions should be plotted to check the directions of these, and the actual numbers should be checked from listings. To be able to check the correspondence between plots and listings, documentation of node/element numbers and coordinates may be required.

B.4.8 Reactions

**B.4.8.1** The reaction forces and moments are normally calculated by the FEM programs and should be properly checked. As a minimum, it should be checked that the total reaction corresponds to the applied loads. This is especially relevant when loads are applied to areas and volumes, and not merely as discrete point loads. For some programs, it is possible to plot the nodal reactions, which can be very illustrative.

**B.4.8.2** A major reason for choosing an FEM analysis as the analysis tool for a structure or structural part is that no simple calculation can be applied for the purpose. This implies that there is no simple way to check the results. Instead, checks can be carried out to ensure it is probable that the results of the FEM analysis are correct.

B.4.9 Mesh refinement

**B.4.9.1** The simplest way of establishing whether the present model or mesh is dense enough is to re-mesh the model with a more dense mesh, and then calculate the differences between analysis results from the use of the two meshes. As several meshes may have to be created and tried out, this procedure can, however, be very time-consuming. Moreover, as modelling simplification can induce unrealistic behaviour locally, this procedure may in some cases also result in too dense meshes. Instead, an indication of whether the model or mesh is sufficient would be preferable.

**B.4.9.2** The need for mesh refinement is usually indicated by a visual inspection of stress discontinuities in the stress bands. Analogous numerical indices are also coded.

B.4.10 Results

**B.4.10.1** Initially, the results should be checked to see if they appear to be realistic. A simple check is made on the basis of an evaluation of the deflection of the component, which should, naturally, reflect the load and boundary conditions applied as well as the stiffness of the component. In addition, the stresses on a free surface should be zero.

**B.4.10.2** Most commercial FEM programs have some means of calculating error estimates. Such estimates can be defined in several ways. One of the most commonly used estimates is that of the error in the stress. The estimated ‘correct’ stress is found by interpolating the stresses by the same interpolation functions used for displacements when defining element stiffness properties.

Another way of obtaining an indication of stress errors is by comparing the nodal stresses calculated at a node for each of the elements that are connected to that node. Large variations indicate that the mesh should be denser.

**B.4.10.3** If the results of the analysis are established as linear combinations of the results from single load cases, the load combination factors used should be clearly stated.

**B.4.10.4** The global deflection of the structure should be plotted with appropriately scaled deflections. For further evaluation, deflection components could be plotted as contour plots to see the absolute deflections. For models with rotational symmetry, a plot of the deflection relative to a polar coordinate system may be more relevant for evaluating the results.

**B.4.10.5** Stresses and strains may be evaluated in nodal points or Gauss points. Gauss point evaluation is generally most accurate, in particular for layered composites, in which the distribution of stresses is discontinuous, and should therefore be applied when possible.
**Guidance note:**
The analyst should beware that Gauss point results are calculated in local (element- or ply-based) coordinates and must be transformed (which is automatically performed in most FE codes) in order to represent global results. Thus, Gauss point evaluation is more time-consuming than nodal point calculations.

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**B.4.10.6** All components of the stresses are calculated, and it should be possible to plot each component separately to evaluate the calculated stress distribution.

**B.4.10.7** The principal stresses should be plotted with an indication of the direction of the stress component, and these directions should be evaluated in relation to the expected distribution.

**B.4.10.8** As for the evaluation of the resulting stresses, the components of the resulting strains and the principal strain should also be plotted in an evaluation of the results of the analysis.

**B.4.10.9** Computed results shall be checked for self-consistency and compared with, for example, approximate analytical results, experimental data, textbook and handbook cases, preceding numerical analysis of similar problems and results predicted for the same problem by another program. If disagreements appear, then the reason for the discrepancy shall be sought, and the amount of disagreement adequately clarified.

**B.4.10.10** Analysis results shall be presented in a clear and concise way using appropriate post-processing options. The use of graphics is highly recommended, i.e. contour plots, (amplified) displacement plots, time histories, stress and strain distributions, etc.

**B.4.10.11** The results shall be documented in a way that helps the designer to assess the adequacy of the structure, identify weaknesses and ways of correcting them and, where desired, optimize the structure.

**B.4.10.12** FEM analysis results shall be verified by comparing them against relevant analytical results, experimental data and/or the results of any previous similar analysis.

**B.4.10.13** Results shall be checked against the objectives of the analysis.
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